

# Evidence-based Crime Investigation. A Bayesian Approach

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## Preface

This dissertation is about evidence and inference in crime investigation. The question is: What can and should "evidence-based" crime investigation mean? My immediate aim is to contribute to the methodological toolbox of crime investigation, but I also aspire to contribute to the concept and standard of evidence in real and public decision-making.

Epistemology, methodology, and the foundational issues of different knowledge disciplines have been my basic intellectual interest since my student days. During the obligatory curriculum for a degree in political science at the University of Oslo, I gradually discovered that my talent, if any, was in methodology and analysis and not in politics. I did not have the maturity or boldness of my fellow much more politically minded students. While they rapidly formed an opinion on how things should be on almost any social or political matter I became stuck in the premises: How did they know that the premises of their opinions were sufficiently certain? Is not the certainty of the premises important if your opinion is to become actual policy, having real consequence to real people? I completed my degree in political science with a thesis analysing central foundational problems of political science (rationality vs. social norms; individualism vs. collectivism). Having "discovered" that the premises for these foundational conflicts were ideological too, the question became: By which criteria may we evaluate the knowledge-claims of public policies? I wanted to pursue the concept and standard of evidence and justification in practical public decision-making. During my search for like-minded students, for funding, and for an interesting kind of problem, I read about the Norwegian Torgersen-case in the newspapers, a Norwegian crime-case from 1958 which could not find rest: Repeated motions for retrial were rejected, but the counsel of defence kept insisting that something was seriously wrong with the evidence-assessment in that case. A group of scientists joined in to add that something was seriously wrong with Norwegian legal evidence-assessment in general!

I had found my problem: Few decision-problems are as acute, complex and consequential than legal decisions about the case-specific value of evidence in a given crime case. I contacted Staale Eskeland, professor at the Department of Public and International Law, University of Oslo, who had worked (and works) tirelessly to have the Torgersen-case reopened. He had carefully collected all the case-documents and did not hesitate to let me use them as sources in a PhD on legal assessment of evidence. He also offered to be one of my supervisors if the thesis was to be worked out in Norway. I am thoroughly grateful for his support and inspiration.

Unfortunately no research-institution in Norway wanted to host what had to

be an interdisciplinary Ph.D. Philip Dawid, professor in Statistics at the University College in London, had no such qualms: He was the Director of a research program specifically wanting cooperation across disciplines, **Evidence, Inference and Enquiry. Towards an Integrate Science of Evidence**

(<http://128.40.111.250/evidence/>), and immediately invited me in. Joining this research program meant having to stay away from my family for long periods of time. But my wise husband (dear Arild!), knowing how much I wanted and needed to pursue my ideas, said I would be a fool not to accept the opportunity so generously offered by Philip Dawid. It was fortunate that I did not understand how much I was to miss my husband and children. It is impossible to thank Mathea, Marius, and Sandra, and my husband enough for letting me indulge in this rather selfish pursuit — I feel very lucky to have them. I am also very lucky to have my parents who always believe that I do the right things even when I do not (oh, you need to go to London to write the PhD? That is probably the best. Do you need money for that?). I thank them all I can for all the support through these years.

The work with the thesis was far from straightforward. I do like to work and do like challenges, but I did at times feel overwhelmed. I simply did not understand how to make sense of the knowledge-situation in bitemark-analysis: While my fellow students had access to reasonably clean data-sets, I had to start from scratch, making my own data from the information offered in pieces of natural prose. This was challenging but also very interesting — it was actually an opportunity to make sense of the cognitive process of natural as well as formal representing and modelling of reality. It unfortunately took a long time before I decided that the thesis had to be just as much an epistemological as a methodological study. Philip Dawid, my initial primary supervisor, may have wished for a more efficient student, but he never questioned the value of my work and ideas. My second supervisor, Dr. Christian Hennig came to be my primary supervisor when Philip Dawid left for a professorship in Cambridge. Christian Hennig is the incarnation of thoroughness and precision, but fortunately also shared my curiosity about methodology. Despite my extraordinary degree of confusion Christian always took me seriously and carefully read and commented my presentations. I am very grateful that both Philip and Christian continued believing in this risky project: Thank you to both of you!

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# Chapter 1

## Introduction

We take for granted that the services of public institutions are based in sound knowledge — that their decisions are based on information and evidence which are *sufficiently complete, reliable, relevant, and coherent* for the case-particular as well as for the proclaimed institutional aims and values. We take this for granted because we trust that the public institution is *ethically* founded — an instrument for doing good rather than doing harm to its subjects — and that it is *rationally* founded — an instrument consciously and strategically organized so as to systematically actually achieve the specified purposes rather than undermining these purposes. We thus take for granted that there exist procedures — more or less explicit and obligatory codes, rules, guidelines, or norms — to standardise the achievement of purposes, or to make it predictable, across individual decision-makers and across individual cases.

I thus trust a scientist at the university to produce sound basic knowledge — because I trust him or her to want to establish true knowledge rather than false knowledge and that he or she is rational in this pursuit, adhering to inference procedures known to support this want; I trust that my general medical practitioner makes a sound diagnosis of my particular complaints and a sound decision about the best treatment for *me* — because I trust him or her to want me to be healthy rather than suffering and that he or she is rational in his practice, adhering to both inference procedures and medical and public health guidelines known to support this want; and, were I to become involved in a legal case, I will trust the judge to produce sound legal adjudication — because I trust him or her to want to establish good law and peaceful conflict resolution based on correct facts and that he or she is rational in this pursuit, adhering to both inference procedures and legal procedures and guidelines known to support this want.

In this dissertation I will concentrate on *crime investigative decisions*: As a

representative of the investigative office serving the legal institution, we trust the investigator to produce sound decisions about the causal mechanism behind an event possibly involving a legal injury — because we trust him/her to want to establish true knowledge about this event rather than false knowledge and that he or she is rational in this pursuit adhering to both inference procedures and legal procedures and guidelines known to support this want.

In other words, given the serious consequences of decisions made by representatives of any public institution, we expect that such decisions are *evidence-based*: Minimally based on evidence being justifiably sufficiently reliable, relevant, and coherent.

This expectance that public decisions are *evidence-based* is the basic premise of this dissertation. And a minimum standard of *evidence-basis* — of what I in this dissertation minimally require of "evidence being justifiably sufficiently reliable, relevant, and coherent" — will apply. The following Premise 1 defines this minimum standard of *evidence-basis*:

#### **Premise 1. A minimum standard of *evidence-basis***

An ultimate decision made by a decision-maker of a public service is *evidence-based* if all the reference-groups and -terms causally, logically, and normatively necessary for the decision are explicit and unequivocal and (a) enable person-independent assessment of the degrees of relevance decided for the events and the concerns involved and (b) enable person-independent assessment of the risk of not achieving the proclaimed aims and, thereby, not protecting the values involved.

Explicit and unequivocal reference-groups and -terms are central to this standard: A reference-group or -term is an abstract or ideational category or collection of individuals (any physical or ideational entity/being) perceived to be equal with respect to a set of properties, qualities or characteristics. Such groups and terms are basic cognitive means — necessary for humans when searching or imposing an *order* on reality, make *sense* of it, or see or give *meaning* to it. Reference-groups and terms are thus always present when we assess, evaluate, and adjudicate claims and arguments. But they are not always conscious or explicit.

What is required for an individual to become a member of a reference-group may be more or less easy to agree on, requiring more or less explication and specification. It will be rather easy to agree on the reference-groups for the sign "chair for sale" attached to a wooden object in a flee-marked, needing little specification of what is meant by "chair" and "sale"; but it is far less easy to agree whether or

not a human being is legally responsible for having violated a given legal code, requiring much more explication and specification. When the groups and categories involved become numerous and complexly intertwined and/or the consequences of sorting an individual in this or that group are grave, the need for explication and specification will increase; if (in such situations) reference-groups or -terms are not made explicit or are left ambiguous, people will be more or less confused: Their trust or confidence that a given classification is correct will be an indirect one, via the degree to which they in general trust the authority or past decisions of the public institution.

The citizens of modern democracies — all convinced that the principles of equality and the right and duty to participate in government apply, and a growing proportion having higher education — will no longer be satisfied by mere appeal to authority and tradition. They will require justification in the terms of reason and logic and other more contextually or locally agreed norms, principles, and terms: Equality and the right and duty to participate requires access to the means used by the decision-maker, the means must be explicit; and the more complex and the graver the consequences of such decisions, the more unequivocal these means have to be. The use of implicit or ambiguous reference-groups and -terms (consciously or not) will in effect prevent people from exercising what they believe to be their rights and duties, estrange and exclude them, and cause them to distrust or lose confidence in these decisions.

Reference-groups and -terms are thus not only basic cognitive means generally necessary for people to make sense of the world and to be able to trust and have confidence; *explicit* reference-groups and -terms are also useful modern institutional means — for legitimizing decisions and have people accept and abide by them; and *explicit* and *precise* reference-groups and terms are useful modern administrative means — useful for assessing whether a decision reached its proclaimed intentions and aims and whether the risk of loss of values was sufficiently low. The claim that the modern citizen requires more than mere appeal to authority to gain trust and confidence in public decisions will be substantiated further in the next section.

*Premise 1.* A *minimum standard of evidence-basis* is thus in effect a reference-term for this dissertation — being the comparison-basis whenever I assess claims and pass judgement on whether such claims are evidence-based or not.

In this dissertation I will, as said, attend particularly to *crime-investigative decisions*: We expect the investigator to produce sound decisions about the causal mechanisms behind given events possibly involving a legal injury; that he/she want to establish true knowledge about these mechanisms rather than false knowledge; and that he/she is rational in the pursuit of this want by adhering to analyti-

cal norms and techniques known to produce true knowledge — or, in practice, knowledge which is justifiably complete, reliable, relevant, and coherent. These decisions should also be evidence-based according Premise 1. But what does it mean to have this kind of knowledge when the event is a *particular* event — when the event is but a single outcome of a highly complex, unknown, and unrepeatable causal mechanism? And what does it mean to have this kind of knowledge when the knowledge is to be used for normative purposes within the legal-institutional context? Which analytical norms and procedures can and should be used when producing knowledge under these analytical and institutional conditions and aims? This is the central questions of this dissertation.

There are of course many *kinds* of crime investigative decisions. In this dissertation I will limit to one particular kind and to one particular subgroup within that kind. I will only study decisions occurring in the final stage of a given crime investigation: *After* the busy initial phase of crime scene investigation, primary information-gathering, and witness-interviewing; when a given set of possible *legal indictments* has been identified; and when the different *means of evidence* are under construction and assessed for their basic — causal-logical — *evidential value* relative to one or more indictments. I will further constrain to decisions about the *evidential value* of means of evidence involving *forensic expert-information* about *physical items* anticipated relevant to the event investigated. I will further concentrate on physical items in the form of *imprints without transferred components (imprint-means)*. To substantiate this relatively broad group — which includes fingerprints, shoe-prints, tyre-prints, tool-marks etc. — I will concentrate on imprints in the form of *human bitemarks on human skin*, hereafter referred to as *bitemark-means*.

The investigative decision about the basic evidential value of any means of evidence involves the assessment of the causal and logical relationships between the information contained in the means of evidence and the indictment — whether the means of evidence is relevant to the indictment, whether it changes the probability or certainty of the indictment. This decision will be used by the prosecutor assigned to the case when he/she is to decide both *whether* and *to which degree* the means of evidence can serve the legal negotiation and adjudication during the trial-phase of the case.

So, immediately preceding the decision about the basic relevance of a means of evidence, the investigator in charge has that

- a relevant *indictment* and its implied conditions have been identified  
(An indictment is a proposition formulated in legal terms claiming that the indicted person has committed a particular act covered by law. This proposition will be argued to be most likely true by the prosecution during the trial-phase; an indictment

will by the court be found proven if the necessary conditions of the indictment are proven to the required legal standard of provability );

- the *means of evidence* (including imprint- and bitemark-means) and its implied conditions have been identified  
(A particular means of evidence is a proposition claiming that a necessary *condition* exists for the case — conditions being logically/causally necessary implications of the terms of the formal legal indictment and otherwise being either positive or normative; fundamental/simple or derived/complex; and legal or extra-legal or a-legal in substance );
- the main body of information relevant to these means of evidence has been identified, collected, and organized; and
- the main investigative tasks remaining are, for each means of evidence,
  - to assess the basic evidential value or relevance with respect to the indictment; and
  - to assess the risk of deciding wrongly about this value.
- the immediate investigative aims being to
  1. contribute to (a) convict the true responsible or (b) acquit the true innocent and
  2. not contribute to (a) acquit the true responsible or (b) convict the true innocent.

The basic question of this dissertation is thus:

**What can and should it mean to have evidence-based  
crime investigative decisions about the evidential value of  
imprint-means of evidence?**

To answer this question adequately I need to identify the analytical and institutional aims and conditions contextualizing the above crime investigative problem. I also need to identify the existing decision-procedure for this problem to assess whether it satisfies Premise 1. Finally, if amendments to the existing procedure are needed, I must assess whether the suggested alternative procedure is compatible with the institutional aims and conditions of the investigative problem. The **sub-questions** studied in this dissertation given this premise are as follows:

### **Sub-question 1: The institutional context of the decision-problem**

What are the analytical and legal institutional aims and conditions of crime investigative decisions about the basic evidential value of means of evidence? Which analytical procedures exist which are compatible with both the analytical as well as institutional aims and conditions? This question is assessed in part I of this dissertation.

### **Sub-question 2: The existing procedure for bitemark-means**

Are the existing crime investigative decisions about the basic evidential value of bitemark-means evidence-based according to the standard of Premise 1? This question is assessed in part II of this dissertation.

### **Sub-question 3: A possible alternative procedure for bitemark-means**

A possible alternative procedure for the problem of deciding the basic value of bitemark-means is one anchored in Bayesian theory. The procedure is justifiably able to protect the analytical and crime-investigative aims and values of the decision-problem. But is it justifiably able to achieve and protect the broader legal-institutional, *criminal case processual*, aims and values? This question is introduced in Part I of this dissertation, where I discuss the use of formal analytical procedures (in general) in light of different and conflicting legal theories on evidence and proof. The question is reintroduced in Part III, where I discuss the suggested alternative procedure (Bayesian Network-based) in light of its ability to achieve and protect the criminal case processual aims and values.

These questions will be further substantiated in the last section of this chapter, when I present the outline of this dissertation.

A final practical constraint concerns the kinds of legal systems: I will only attend to the above decisions made by investigative services within European jurisdictions formally obliged by the European Convention on Human Rights (ECHR).<sup>1</sup> Premise 1 and the questions of this thesis relates particularly to ECHR's article 6.2: "Everyone charged with a criminal offence shall be presumed innocent until proved guilty according to law".

In addition to the main Premise 1 there will be two further premises operant during the analyses of the questions of this dissertation: Premise 2 concerns the

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<sup>1</sup><http://www.hri.org/docs/ECHR50.html>

perspective of the criminal case process — that it may be seen to be a *sequential decision-process*; Premise 3 is an extension of Premise 2 and concerns the conflict between (a) the values associated with analyses and decisions about positive properties (about what *is*, *was*, or *will be* for someone or something) and (b) the values associated with analyses and decisions about normative properties (about what *should be*, *should have been*, or *should become* for someone or something).

### **Premise 2. The criminal case process as a sequential decision process**

To say that a decision process is a sequential decision-process is to say that the choices available at one interval of time of the process are dependent on or conditioned by the choices made at the previous interval of time.

Time is essential dimension in the organization of the criminal case process: The questions and issues attended to by the legal agents at the end of the trial-phase of the case process are different from the questions and issues attended to by the crime investigators at the end of the crime investigative phase — which in turn are different from the questions and issues attended to by crime scene personnel and forensic experts. The difference concerns the kind of purpose, the logical or causal order, the degree of simplicity, and the kind of substance of the information needed for answering the questions: Questions about what is *positively true/false* for the case must be answered before one can identify and answer questions about what is *normatively right/wrong* for the case; and questions about *fundamental* and *simple* facts and standards must be identified and answered before one can ask and answer questions about *derived* and *composite/complex* facts and standards. In addition there will be questions about aspects being more or less legal or a-legal in nature — questions involving terms or relationships having intensions familiar only to legal professionals or familiar to either lay people in general or other groups of professionals. Particularly during the latter part of the trial-phase, the questions will in practice be complex and it will be difficult to separate them into one or the other kind. Analytically, however, it is possible to sort the questions or claims occurring during the different phases of the criminal case process along the three dimensions signified above:

**positive-normative:** A claim may be positive or normative with respect to its degree of dependence on contextual/situational norms and principles: A positive claim states that a given property or characteristic, or set of such, *truly does* exist for an individual (any physical or ideational entity or being (person, thing, case, relationship, etc.)), i.e., *independent* (practically) of contextual/situational norms and principles and personal preferences; A

normative claim states that a given property, or set of such, **rightly should** exist for an individual, i.e., *dependent* on contextual/situational norms and principles (legal and social) (but still independent of personal preferences);

**legal-a-legal:** A claim may be legal or a-legal with respect to the substance of the claim: A legal claim states that a given property of a legal specific nature does or should exist for an individual; An a-legal claim states that a given property of an a-legal nature — having a common social or another disciplinary meaning — does or should exist for an individual;

**foundational-derived:** A claim may be foundational or derived with respect to its degree of necessity relative to another claim: A foundational claim states that a property necessary for a derived property does or should exist; A derived claim states that a property which presumes the existence of another property does or should exist.

Analytically, the crime investigator in the crime investigative phase of the criminal case process can be said to attend predominantly to positive claims about foundational and a-legal properties. Moving on to the trial-phase, the prosecutor, defence counsel, and the judge/jury in the trial-phase will attend to both positive and normative claims about derived and legal as well as a-legal properties (assuming that the required foundational properties exist): At the beginning of the trial phase, the attention will predominantly be on positive claims, over time the attention will gradually move on to predominantly normative claims.

According to the perspective that the criminal case process is a sequential decision process, the questions or claims attended to by the crime investigators will condition the choices available to the prosecutor, the defence counsel, and the judge/jury. The crime investigator with his/her questions at the end of the crime investigative phase is well, but not perfectly fully, informed, and has good, but not perfectly correct, expectations about the questions which have been attended to by the crime scene personnel or forensic experts or which will be attended to by the prosecutor, defence counsel, judge/jury. The fuller and more correct the information and expectations are about the choices which have been made or will be made, the less the risk will be for deciding wrongly in the final decision. This dependency constitutes reason to seek to control that the information needed for answering the next set of questions is in fact established. This is the explanation why legal procedures exist and is so important during case-management. The Premise 2 of this dissertation is thus:

**Premise 2: The criminal case process is a sequential decision-process**  
The choices made by the crime investigator during the investigative phase

will condition the choices available to the prosecutor, defence-counsel, and the judge/jury during the trial-phase.

**Premise 3. The conflict between the values of positive analysis the investigative phase and the values of the normative analysis in the trial phase.**

The ultimate aims of the criminal case process are that the parties and the public accept and abide by the decisions made and that the public's confidence in the legal institution is maintained. In the legal discourse on evidence and proof, as will be discussed further in part one of this dissertation, there is visible a foundational conflict about the best means to achieve these aims: The "protectionists" insist that negotiation and conflict-reduction through consensus-building are the best means; the "probabilists" insist that accuracy, precision/unambiguity, and objectivity are the best means. Particularly in the public discourse in the aftermath of controversial court-decisions one may get the impression that these two sets of means are incompatible — that one must choose among them.

The third premise of this dissertation acknowledges the conflict but holds that both sets of means are necessary for achieving the ultimate aims of the criminal case process. The premise is an extension of Premise 2., and concerns the conflict between the values aspired for analysis of positive claims and the values aspired for analysis of normative claims.

Analyses and decisions about positive claims — that a given property or characteristic, or set of such, **truly does** exist for an individual (any physical or ideational entity) — aspire to be *true* for all people at any time and place, *independent* of contextual/situational norms and principles and personal preferences. Complete truth is impossible because the world is complex and our cognitive powers are fallible. Instead we aspire highest possible *certainty*, dependent on only one fundamental and commonly shared set of standards and norms — that of logic and causality. Certainty is associated with the values of *accuracy*, *precision/unambiguity*, *objectivity* and *impartiality*. These values appeal predominantly to people's epistemic needs.

Analyses and decisions about normative claims — that a given property or characteristic, or set of such, **rightly should** exist for an individual (any physical or ideational entity) — aspire to be *good* for a specific group of people in a given interval of time and space, *dependent* on several sets of context- and situation-specific norms, principles, and personal preferences. Complete good is also impossible, again because the world is complex, but just as much because there will be several different sets of norms and interests which may also conflict

with each other due to groups of people having different contextual/situational needs. Instead *right* is aspired through negotiation of the weight or *degree of relevance* which should be ascribed to each set of norms and interests, the final balance between them *agreed on* among those affected. In contrast to truth and certainty, good and right are ultimately associated with the values of *emphatic consideration of each and all sets of norms, consensus, and conflict-reduction*. These values appeal predominantly to people's *emotional* and *social* needs.

It is not difficult to recognize that the values aspired when analysing and deciding about positive claims are uncomfortable companions with the values aspired when adjudicating normative claims: Positive analysis draws the attention to both practical as well as theoretical *uncertainty*, while normative analysis draws the attention to practical *certainty*; an overt attention to accuracy and precision for *truth* and *certainty* are not directly conducive to consensus and conflict-reduction for contextual/situational *good* or *right*. But, on the other hand, it is impossible to have good and right for someone with respect to contextual/situational norms and interests if these are not fundamentally, causally/logically, relevant to the case: The values of accuracy, unambiguity, objectivity, and impartiality are thus also relevant, indirectly, when adjudicating the good and right in a context/situation.

Above I claimed that questions about what is positively true/false for the case must be answered *before* one can identify and answer questions about what is normatively right/wrong for the case. In the extension of this I claim that the values aspired for positive analysis function as *premises* for normative adjudication: Both *epistemic* and *emotional/social* needs must thus be satisfied for people to have trust and confidence in legal decisions — values associated with each *must* therefor somehow be emulsified. The third premise of this dissertation is thus

**Premise 3: The criminal case process must emulsify truth and good.**

The values aspired for positive analysis are only indirectly compatible with the values aspired for normative analysis, but because the positive analysis is a necessary premise for the normative analysis, the two sets of values must somehow be emulsified during the criminal case process.

In the next section of this chapter I will justify and substantiate further the concept of evidence-basis preliminarily specified in Premise 1. In the last section I provide an outline of the parts and chapters of this dissertation.

## 1.1 A concept of evidence-basis relevant for crime investigative decisions.

According to Premise 2 and Premise 3, the crime investigator in the crime investigative phase of the criminal case process is to determine the basic causal mechanism (the causal agents, human and other, and their relationships) of a given particular event — attending predominantly to positive claims about more foundational and a-legal properties and aspiring truth for these claims in the form of highest possible accuracy, precision/unambiguity, objectivity, and impartiality. The investigator will use three basic types of information or evidence: (1) witnesses' (lay and expert (including crime investigative)) *sense-observations*; (2) witnesses' *interpretations* (stories, hypotheses, models, theories, etc.) of the sense-observations; and (3) lay- and expert-witnesses' *reasoning abilities* (logical, cognitive, emotional, etc.) for structuring the sense-observations and interpretations.

Any analysis must use these types of evidence. But the *standard* required with respect to their accuracy, precision/unambiguity, objectivity, and impartiality will vary — depending on how important it is to have the problem solved and on how serious the consequences are: The more important it is to make a decision and the more serious the consequences, the more accurate, precise/unambiguous, objective and impartial we require the observations, interpretations, and the reasoning to be.

Crime-investigative decisions about the basic causal mechanism of events possibly involving a legal injury is undeniably both important to make and will have serious consequences. The question about what should be the appropriate standard of the instruments/means of evidence is thus a reasonable question.

So far, the concept of *evidence-based crime-investigation* does not exist. Neither the discipline of crime- investigation nor its main user-discipline, jurisprudence, has invested much in developing procedures justifiably suited to secure a high standard of accuracy, precision/unambiguity, objectivity, and impartiality when deciding about the truth/certainty of positive aspects or properties of a case. The criminal case process does indeed have procedures, but these attend predominantly to the standard of adjudication and decision about the normative aspects or properties of cases — ensuring that the adjudication and decision is sufficiently *good and right* in terms of emphatic consideration, negotiation, consensus-orientation and conflict-reduction.

And the criminal case process does of course operate with standards for what is sufficiently true, certain and probable, but this standard is not formally regulated by procedures nor sought consistently justified in epistemological terms. Justification is usually by ad-hoc reference to the justification existing for the standard of good/right when adjudicating and deciding about normative aspects and prop-

erties. The unhappy consequence is that peoples' basic epistemic, causal/logical, needs are less cared for. If such needs are, as stated in Premise 3 above, just as important as situational emotional and social needs, the inattention will affect the ability to secure the public's overall confidence and trust in the ultimate decision at the end of the criminal case process.

How then can one epistemologically justify a chosen standard of certainty and probability given the analytical and institutional conditions and aims of crime investigation?

In this dissertation I suggest that we study the medical clinical diagnosis situation: To make a clinical diagnosis is to make a decision about the most likely causal mechanism of a given set of symptoms in a given patient — the purpose being to serve the later identification, analysis, and balancing of medical, ethical, quality-of-life, and economic concerns, as well as the final decision about the best course of action for the patient. The medical clinical diagnostic decision-situation is analogue to the crime investigative decision-situation: The latter is to decide about the most likely causal mechanism of a given set of information in a given crime case — the purpose being to serve the later identification, analysis, and balancing of legal, ethical, social, and economic concerns, as well as the final decision about the distribution of responsibility and kind of sanction. The two diagnostic situations are thus analogue with respect to the immediate and mediate aims, but also with respect to the analytical conditions: Both concern events which are singular outcomes of unknown and unrepeatable causal processes. So, both the situations may be seen as parts of a sequential decision-process as specified in Premise 2. above, a process which (a) involves analyses and decisions about different kinds of aspects or properties (positive and normative, foundational and derived, and discipline-specific and general) and (b) must cater to both basic common epistemic needs and situation-specific conflicting emotional and social needs; and both have to make decisions which will have real and possibly grave consequences to real people.

I will therefore study the notion of *evidence-based medicine* as this is understood within the public health context. The standard is increasingly being enforced in order to ensure that only medically, ethically, socially, and economically justifiable diagnostic procedures and medical therapies are offered by public health institutions. The notion of evidence-based diagnosis is thus believed to help us towards specifying what it can and should mean to have evidence-based crime-investigation.

In order to arrive at evidence-based diagnosis we must start with evidence-based decisions about treatment because the latter is the decision for which the concept was originally developed and is at its most explicit. Only then may we proceed to evidence-based diagnosis. Having this notion clear I will turn to an important subgroup of diagnostic decisions: Decisions which must be made, but

which have no access to justification in the form of large scale studies performed satisfactorily according to a known inference procedure. This situation is relatively frequent in the medical context and is usually considered to have the poorest kind of evidence-basis. In the crime investigative context such situations are perhaps the typical situation (but you may find evidence-based decisions here too, mainly in forensic genetics).

### **1.1.1 Evidence-based decisions about the most relevant therapy for a given patient**

The principle of evidence-based medicine is an old one, but became familiar to lay people during the 1990's: You should only prescribe a particular therapy to an individual patient with a given diagnosis if there exist *sufficient* evidence that it has a net positive effect on patients similar to the patient at hand, similar both with respect to diagnosis and other relevant characteristics; *sufficient* evidence being the results of large scale studies performed satisfactorily via inference methodology which include risk-assessment to the concerns identified for the decision.

An evidence-based decision about the most relevant treatment depends critically on the decision about the most likely diagnosis — the decision about the most likely causal mechanism — of the patient's symptoms. This diagnostic decision must therefore be evidence-based as well: You should only use a diagnostic test and/or expert-knowledge to diagnose an individual patient if there exists *sufficient* evidence that the diagnostic test and/or expert-knowledge reduce the uncertainty that patients similar to the one at hand have or do not have the condition tested for; *sufficient* evidence being the results of larger scale studies performed satisfactorily via inference methodology which include risk-assessment to the concerns identified for the decision.

The main justification for this principle in medicine is ethical. Both the decisions about the most relevant treatment and the most likely diagnosis are uncertain decisions which, if wrong, may have serious consequences to the patient's health and quality of life. The uncertainty stems from the strong and unknown conditioning of the case: In principle nothing is similar to this patient — it is his or her particular kind of symptoms as these have been produced under conditions largely unknown to the clinician and as these are informed on by the patient and various medical heuristics. From this highly conditioned set of information the clinician must make critical decisions, first about the most likely diagnosis of the patient, and then about the best treatment for this patient. To avoid doing harm to the patient, the clinician is responsible that the decisions are accurate, precise, objective, and impartial to a known high standard — a standard specified in decision-procedures installed to guide individual decision-makers, standardise high

quality decision-making across individual clinicians and thus minimize overall risk of harm. An identified and explicitly specified *standard* of evidence in the form of more or less situation-specific decision-procedures is then an ethical strategy.

Another purpose of the principle is to ensure the public's *trust* in the public health service: A decision based on the best possible evidence about effect will not only avoid doing harm but also signal that it wants to do good: Evidence-based medicine may, it is believed, install a public confidence that the public health institution takes its patients seriously, and, by extension, that the government takes its subjects seriously. In this perspective, the principle is an instrument of the state to demonstrate that it intends to keep its part of the "contract" with its subjects.

But it is a third purpose which made the principle explicit, more widely known, and, some would claim, really made it consequential to the public health sector: It is an effective budgetary instrument to a government with a tight budget; "We can only fund therapies and diagnostic tests documented to be effective." The rapid increase of medical knowledge and the increase in the availability of expensive diagnostic instruments and therapies, coupled with a decreasing budget, force the need to prioritize and to find criteria for choice. Requiring that public health decisions should be "evidence-based effective for the purpose" presented itself as handy criterion: Medically safe, ethically sound, confidence-installing, and economically sound.

The principle of evidence-based medicine has thus become a central strategic steering-instrument in the public health sector.

But what does this modern notion of evidence-based medicine imply? There are several kinds of implications depending on the purpose of the medical decision, but one feature is common: It requires an explicit ranking of the *quality* of the evidence; with respect to both positive and negative outcomes; where the outcomes include (a) strictly medical outcomes, (b) quality of life outcomes, and (c) the economic costs of the interventions.

Several systems for grading the quality of evidence exist, each offering different criteria for grading the quality of different kinds of evidence. In this dissertation I will let the GRADE-system, adopted by the World Health Organization and the Cochrane Collaboration (which systematically reviews current status of medical knowledge) and recommended by the British Medical Journal to its authors, represent the interpretation of what it means to have evidence-based medicine.<sup>2</sup>

GRADE suggests that both the *recommendation of a given intervention* and the *quality of the evidence of effect of the intervention* should be graded according to the following criteria:

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<sup>2</sup><http://www.gradeworkinggroup.org/>  
<http://www.cochrane.org/> <http://www.bmj.com/>

<http://www.who.int/>

- A *strong recommendation* to intervene or not to intervene with a specific diagnostic strategy or a therapy in a given case is justified when the overall evidence is of high quality and when the beneficial outcomes of the intervention/non-intervention clearly outweighs the undesirable outcomes;
- A *weak recommendation* to intervene or not to intervene in a given case is justified if either the overall evidence is low quality or the balance of beneficial and unwanted outcomes is even or uncertain (Guyatt, et al. 2008a, 2008b, 2008c).

The GRADE-system's *overall evidence* contains any information relevant both to strictly medical outcomes and to quality of life-outcomes and economic costs to the individual patient and to the health-care system. The *quality of the overall evidence* depends on both

1. the quality of the expert-knowledge based evidence offered for each of the possible medical outcomes (positive and negative) in a given case and
2. the needs and values (positive and negative) important in the given case.

The GRADE-system suggests that the quality of the relevant *expert-kind* of information should be assessed according five factors:

1. The study-designs' ability to produce unbiased results;
2. the studies' actual production of unbiased results;
3. the relevance of the study to the clinician's situational problem;
4. the consistency of evidence across studies;
5. the number of studies available or the sample-sizes of the studies available for a given outcome. (Guyatt, et al. 2008a, 2008b, 2008c)

Ideally, a clinician's recommendation to pursue a given therapy for a given patient should be based in knowledge from large scale randomized controlled trials showing consistent, complete, and directly relevant large benefits and few harmful effects with respect to not only health or medical concerns, but also with respect to life-quality and ethical concerns and economic costs. This highest possible evidence quality will of course not exist in practice. A continuum of evidence-quality will exist down to the poorest quality situation — the situation in which a poorly trained and experienced clinician simply dictates a treatment based on his own implicit and more or less justified opinion of positive medical effect only and without accounting for extra-medical concerns such as value of life, ethics, or costs. The GRADE-system

thereby signals that the individual clinicians or expert's opinions based solely in own clinical experience — which used to be sufficient for recommending a given therapy to a particular patient — should be classified as very low quality evidence:

Systems that classify "expert opinion" as category of evidence [...] create confusion. Judgement is necessary for interpretation of all evidence, whether that evidence is high or low quality. Expert reports of their clinical experience should be explicitly labelled as very low quality evidence, along with case reports and other uncontrolled clinical observations. (Guyatt, et al. 2008; 925)

The above GRADE-system for ranking quality of evidence is intended for medical decisions about the best possible treatment or therapeutic strategy for a given patient with his or her health-symptoms and life-situation and for a given amount of institutional resources. Is this system relevant to crime investigative decisions about the basic causal mechanism of a crime event? No. If I may force the analogy for the sake of argument, it is more relevant to the ultimate legal decision with its aim of balancing conflicting legal and a-legal concerns. Indeed, both the clinician and the judge or jury need to decide about uniquely conditioned cases; by case-information being equally uniquely conditioned; and the consequences of wrong decisions are equally serious and in the same ways. But the analogy is forced. The judge obviously does not and will not ever have the above kind and quality of evidence to support the ultimate legal decision. As explained in the previous section, there are of course quality-criteria for decisions about the best balance of legal and a-legal interests, but these are different from those relevant and possible for medical decisions about best treatment.

The quality-criteria for decisions about treatment are thus less relevant for crime investigative decisions about most like causal mechanism. We must instead study the criteria specified for clinical diagnosis.

### 1.1.2 Evidence-based decisions about most likely diagnosis

*Diagnosis* is an originally Greek term which refers to "discerning" or "distinguishing", meaning "to know thoroughly": "dia-" indicating "apart" and "-gnosis" indicating "to learn" (<http://en.wiktionary.org/wiki/diagnosis>).<sup>3</sup>

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<sup>3</sup>Site accessed in August 2011.

The modern term is most often used in the medical context, but is used in other contexts as well as it refers to the general process of learning about causes and effects for discrimination or differentiation between the possible causes of a given set of observations. "Diagnosis" thus also covers the crime investigative process of differentiating between the possible causes of "traces" (a "trace" being just the legal-contextual name given to an *observable effect* of some causal process).

A decision about the most likely diagnosis or causal mechanism must use available information in the form of both lay persons' experiences, diagnostic test-results, and expert-observations. GRADE has naturally much more to say about the grading of quality of evidence in the form of diagnostic instruments and expert-knowledge than that of lay-person observation. A lay-person or patient's reported observations may, just like other kinds of information, be more or less accurate, truthful, and relevant to the diagnosis in question. And procedures for assessing the quality of lay-witness information do indeed exist. But in this dissertation I will limit the attention to information in the form of diagnostic test-results and experts-observations and to the systems for grading quality of such information,

There are two important challenges to systems grading the quality of evidence or information for diagnostic purposes: (1) the number of diagnostic tests and expert-observations needed for each case is usually more than one; and (2) the number of directly relevant high quality studies are much fewer than at the treatment level — due to the increased contingency.

Of course a decision-maker may happen to have a case for which there exists both sufficiently relevant and sufficiently accurate expert-knowledge in the form of large scale studies including consequence-analyses. Then quality-assessment criteria similar to those used for choice of best treatment can be used. But this kind of ready-made high quality evidence is rare.

One needs criteria relevant for the normal situations in which the relevance and/or the accuracy of diagnostic tests and experts is less than perfect.

As for the decision about treatment there will be two main concerns when deciding to subject a patient to a diagnostic test or expert: (1) what is the *accuracy* of the diagnostic test or the expert? What is the test's or expert's ability to differentiate between individuals having and not having a condition? What are the rates of false positives and false negatives?; (2) what are the consequences of the test-result or expert-decision to those involved?. Sackett and Haynes (2002) identified four relevant questions:

1. Are test results in the true positive group different from the results in the true negative group?
2. Are test positive/negative individuals more likely to be true positive/negative?
3. Are test results really differentiating true positives from true negatives in the kind of situations encountered in practice?
4. Will the overall benefit in cases in which the expert-knowledge or test is used be better than the benefits in cases not using the expert-knowledge? (Sackett and Haynes 2002)

But this scheme cannot be a general criterion: Studies are usually either answering only one or two of these questions and might be differently relevant to the case at hand.

This is a challenge equally present to both a decision-maker in the medical context as well as the crime investigative contexts. One might claim that the crime-investigator is more seriously affected by this challenge: The causal relationship sought in the crime investigative context is that between a particular human being and the observable effect of his or her being in a particular delineated time and space; the causal relationship sought in the medical context is that between a physical condition and its observable physical effect. It might be argued that the complexity of the causal path between the agent and its effect, the level of particularity needed of the causal agent, and the possibility of having basic detailed knowledge of the causal mechanism make the two diagnostic situations different.

I agree that the additional time and space requirements are peculiar to the crime investigative situation. But the causal problem independent of these is similar. Neither the need for very small subgroups with fewest possible individuals nor the possibility of having detailed knowledge of the mechanism prohibits the establishment of diagnostic tests or expert-knowledge which with high accuracy may differentiate between positives and negatives. That such tests or expert-knowledge does not exist for common kinds of "symptoms/traces" is a problem due to the experts not yet having studied the mechanism for the forensic purpose. The existence of accurate tests for including/excluding individuals with respect to their DNA-profile on a certain set of genetic markers suggests that the both the issue of level of individuality and the issue of basic knowledge of relevant markers may be dealt with.

The main challenge to the decision-maker at the diagnostic level is then that general studies of the accuracy of tests and experts may be few and variably relevant to the case at hand.

If there exist studies of the accuracy of tests or expert-knowledge which are judged by the decision-maker to be both sufficiently accurate and relevant for the case at hand, then the decision to subject the patient or the case to the diagnostic test or the expert will be conditioned by (a) the resources available, (b) the consequences of subjecting persons to the testing, and (c) the consequences of the test-results to the persons involved. The last is more relevant to the clinical than to the crime investigative context: If effective treatment is not available for a condition having a late onset and if the baseline risk for the patient is even or smaller, a patient may choose not to take the test (a negative result would be good for all patients, but a positive result would be good only for those who believe they can have a good life despite waiting for the condition to manifest). This concern is not relevant to the crime investigative context. The second condition, about subjecting people to testing, may be the most relevant to the crime investigative context, where such tests may invade their legal rights.

The GRADE-system suggests the following criteria for ranking the quality of diagnostic tests and expert-knowledge:

- The design of the accuracy-study or the performance in particular studies may produce results with different degrees of bias: The decision-maker has access to good quality evidence of the accuracy of tests and experts if the study involves representative and consecutive cases in which classification status is uncertain (the kind of cases regularly encountered in forensic situations); a comparison between the approach under study and an alternative approach or a gold standard; existence of appropriate blinding mechanisms; a clearly described process of case selection; and having cases being similar to the cases in the reference standard;
- The accuracy study may be differently relevant to the case at hand: A good quality study for the decision-maker is a study directly relevant to the case at hand by the cases being similar and by the consequences of testing positive and negative (correctly or falsely) are similar.
- The consistency of the accuracy measures across separate studies of the same and relevant expert-decision may vary: A set of studies represents good quality evidence to the decision-maker's particular case if the accuracy measures are not too divergent or if any larger divergence may be explained by relevance issues;
- The number (and their sample-sizes) of accuracy studies available to all the relevant sub-decisions in the given case: The decision-maker has access to good quality evidence of overall accuracy if there are several studies (all with sufficient sample sizes) for each relevant sub-decision in the given case. (Schuneman et al. 2008)

These are then the criteria suggested by the GRADE-system to be relevant for the decision-maker in the normal situations in which either the

relevance or the accuracy of diagnostic tests and experts is less than perfect. The criteria above does not specify that the diagnostic opinion of an individual expert constitutes the poorest quality evidence, but we may assume that this is so for diagnostic decisions as it was for decisions about treatment.

### **Diagnostic guidelines for best practice**

There is one more heuristic available for diagnostic decisions in the medical context — given that there are some knowledge from systematic studies available about a given disease: A physician has access to international or national *guidelines* specifying the criteria or the sub-conditions necessary for a positive or negative decision. This is at least the case for the more common or more serious conditions. The guidelines or "best practice"-instructions are developed by boards the mandates of which are to standardise the performance of individual clinicians — to ensure as few misdiagnoses as possible. The individual physician cannot be expected to have all the relevant knowledge about all kinds of diseases integrated in his or her knowledge-basis. And neither may one expect the physician to derive the criteria by himself each time he or she faces a new patient. There simply is no time for that. Boards of guideline-developers are thus given this task of (a) investigating the existing knowledge about a given condition, its sub-conditions, and its most frequent effects in terms of symptoms, and on this basis (b) formulating the best-practice or evidence-based diagnostic procedure for situations in which a given condition is suspected. The bitemark-procedure I will suggest in the last part of this dissertation is comparable to these guideline-instruments in medical context: It is intended as a best-practice instrument to assist the investigator facing a case with a bitemark on human skin.

#### **1.1.3 Evidence-based decisions about most likely diagnosis by expert-opinion alone**

The above criteria are relevant if the decision-maker actually *has* access to some studies of accuracy of tests and experts. Now we must move to what the GRADE-system has graded as the poorest evidence situation: The situation in which the decision-maker only has access to expert-opinion about the correct diagnosis. In this situation no standard test exists, but a certain level of knowledge is agreed to exist with respect to the causal mechanism.

GRADE has not formulated any system for this subclass of diagnostic situations. Yet this is not an uncommon situation — not in the medical contexts and is perhaps the normal situation in the crime investigative context. Should the decision-criterion in such a situation always be to avoid positive diagnosis? This is clearly not the practice. Positive decisions are daily made on the basis of expert-opinion alone. What can and should be the criteria for these situations? An obvious candidate is that the decision-maker should only use the expert which reliably and truthfully represents a body of knowledge sufficiently mature for the diagnostic purpose. But how should the decision-maker differentiate between more or less reliable experts and more or less mature bodies of knowledge?

We expect that an expert has a certain amount and variety of phenomenal and methodological knowledge. Due to this we expect that an expert will be more accurate than a non-expert with respect to exclude or include particular instances in their correct category — and better at it than a randomizing mechanism, like tossing a coin. The more serious the consequence of a wrong decision, the more accurate will we require the expert to be.

But having "expertise" is not like having a certain amount of hormone in the blood: Instead a range of more or less subtle criteria goes into the assessment whether some professional person is an expert or not. For someone not knowing the expert discipline it is not easy to separate the more accurate from the less accurate expert. O'Hagan et al. (2006), although primarily interested in the premises for best elicitation of experts' probability judgements and resting on cognitive theories and experiments about both non-experts' and experts' judgements under uncertainty, suggest the following criteria:

An expert has access to his/her own sufficiently large pool of relevant particular instances which are sorted into already developed classification-systems. This pool forms a stable basis for estimating the probability of new instance belonging to this or that sub-group (a basis not being affected by factors known not to affect it — such as media attention or own interest);

he or she has access to a sufficiently large pool of *markers* or characteristics by which to sort a new instance into a given sub-group (a sorting which appropriately accounts for conjunctions, basis and base-rates, sample-sizes, and imperfect correlation);

he or she has reached a certain stage of causal understanding of the relationship between the basic components of a relevant mechanism, knowing the basic facts about the components, but equally or more occupied with understanding the relationships between these components under different conditions;

- his or her normative/methodological knowledge is just as developed as his or her substantive knowledge;
- he or she is able to assess a problem analytically when that is needed: Consciously and strategically adhering to rules of logic and probability in situations where accuracy is explicitly required
- he or she is able to assess a problem intuitively or creatively when that is needed — not attending strictly to rules of logic/probability, and possibly violating these in situations where strict accuracy is less an aim;
- he or she is aware of how specification of a hypothesis affects the assessment of both initial and conditioned probability assessments;
- he or she is able to express adequately modest recommendations in problem-situations needing accuracy, but where the components of the problem itself are inherently indeterminate: Accurate expert-performance is easier to achieve if the agents are inanimate entities than if the entities are human beings. O'Hagan et al (2006; 27, 52-55),

The ideal expert is thus a professional with the above characteristics: He or she faithfully represents the substantive knowledge of his or her subject discipline and the variety of strategies differently suited to different problems. The ideal expert is thus like any material diagnostic test — independent of aspects irrelevant to a given diagnostic problem. Any given ideal expert would give the same conclusion to a given problem as any other ideal expert.

But experts are not ideals and the criteria above are not directly assessable of any given individual expert (accuracy in specified problems may be assessed). Instead we assess the expert by his or her general and purpose-specific professional training and experience; by his or her performance in similar cases and in academic work.

In diagnostic situations in which the decision maker only has access to justification in the form of expert-knowledge, a common *practical* solution is to assess the kind of justification generally possible by the expert-domain before consulting an individual expert: Is the general level of the expert-domain mature, but just not yet had the opportunity to study the particular aspect relevant to the case at hand? Or is it generally immature, primarily busy with the basic sorting of the elements of a phenomenon and not yet ready for study of relationships? But to be able to differentiate between mature and immature knowledge you need to know the criteria by which to differentiate sufficiently and not sufficiently justified knowledge claims.

In the medical context, the decision-maker is trained within the same basic scientific academic context as the expert of the expert-domain: The

decision maker and the expert will, by having the same basic training in substantial medical knowledge and methodological norms, agree on the criteria differentiating mature from immature knowledge; and they will have the same expectance with respect to what it means to have a sufficiently sound justification for a knowledge claim. This agreement on (a) *norms for good knowledge-production* and (b) *criteria for good diagnosis* is itself contributing to a predictable standard of evidence with respect to diagnosis-decisions.

This agreement on the basic norms for separating "good" from "bad" knowledge is the motivation for the argument in this dissertation, that also a decision having no access to large scale studies can be evidence-based: It is evidence-based if the decisions-maker adheres to the *epistemological and inferential norms underlying* the procedures and techniques required for good large scale studies — norms that induces conscious and explicit choice of reference groups and terms; explicit justification of probability of the symptoms/information under each possible diagnosis/hypothesis; and explicit assessments and statements about the risks of being wrong and doing harm. This agreement on the basic norms of knowledge production is thus also the motivation for the formulation of Premise 1. in this dissertation.

But in the crime investigative context, one may not assume that the different decision-makers agree on the basic norms of knowledge-production. A crime-investigator is usually trained at a police-academy primarily educating first-line police-officers. Officers wanting to become crime-investigators receive further training, but the curriculum for analysis and inference has just recently started to aspire that of academic institutions. A crime-investigator may thus not be expected to share the same norms as the scientific experts assisting investigation. In addition, the crime-investigator is to serve another kind of expert-knowledge, namely the jurist. The latter has yet different norms and criteria for knowledge-production. Jurisprudence of course knows how to differentiate between good and bad *legal* adjudication and has a firm expectation of what it means to have a sound legal justification. But the criteria for differentiating between god and bad legal adjudication are not the same as those for differentiating between good and bad knowledge-decisions.

But despite being under this kind of cross-pressure of needs and interests I will in this dissertation hold that also crime-investigative decisions both can and should be evidence-based to the minimum standard specified in Premise 1. The preliminary standard of evidence-basis particular to the crime-investigative decision about the causal mechanism of a crime event may thus be formulated as follows:

**Premise 1a. A basic standard of evidence-basis for crime-investigative decisions**

A decision about the basic causal mechanism of a crime event is *evidence-based* if all the reference-groups and -terms causally and logically necessary for the decision are explicit and unequivocal and (a) enable person-independent assessment of the probabilities of the events involved and (b) enable person-independent assessment of the risk of deciding wrongly about the causal mechanism — thereby contributing to (i) the conviction of a true innocent person or the acquittal of a true responsible person; (ii) the reduction of resources available to other cases; (iii) the public losing trust and confidence in the crime investigative services and the legal institution.

This is then the minimum standard for evidence-based crime-investigation and is the standard referred to when I in this dissertation study and evaluate existing and alternative inference-procedures for crime investigative decisions about the basic causal mechanism of crime events.

## 1.2 Overview of the dissertation

In **Part I** of this dissertation I will study the epistemological and legal institutional conditions and aims relevant when assessing existing methodologies or *inference-procedures* for crime investigative decisions or when constructing new ones. The question in this part is:

**1. What are the epistemological and institutional conditions, aims, and values differentiating inference in the legal context from inference in the scientific context?**

This kind of question must be addressed in any study aiming to construct an inference-procedure for a given practical decision-problem. I argued above that in the medical context it is the agreement about the basic norms and criteria for good diagnosis which ensures the minimum standard of evidence in situations lacking justification in the form of relevant large scale studies via statistical techniques. The construction of evidence-basing diagnostic procedures for such situations in the medical context will usually *not* be met with opposition — the users are already familiar with the concepts and

technical heuristics of methodological instruments. This is unfortunately not the case in the legal context: In particular, any inference-procedure exploiting formal heuristics will most likely be met with scepticism or even be seen as a threat to the ultimate aims and values of legal adjudication.

The first part of this dissertation tries to explain this resistance by studying the foundational issues connected to concept of evidence and proof within jurisprudence. There are three chapters in part I: **Chapter 2** introduces the concept of evidence and inference/proof, first in the terms of epistemology and methodology and then in the terms of jurisprudence. The history of the legal notions of evidence and proof is presented and a central dimension of conflict or a *jurisprudential foundational problem* is identified. **Chapter 3** presents what I believe to be the catalyst of the modern expression of the foundational problem in legal theories of evidence — namely the arrival of the notion of subjective or personalistic probability. In **Chapter 4** I present the positions held with respect to aspects of the foundational problem: The resistance existing in jurisprudence to formal approaches for assessing evidence is explained; and the position of this dissertation is argued —i.e. that formal approaches are conducive to the needs, aims, and values of the criminal case process *if* these are constrained to the crime-investigative phase of that process.

In **Part II** of this dissertation I proceed to study the subgroup of crime investigative decisions focussed on in this dissertation: Decisions about the evidential value of means of evidence involving (a) imprints without transferred components and (b) expert-knowledge for diagnosing the causal object and the time of occurrence of imprints. To illustrate the inference-structure of this group of inference problem I will use human bitemarks on human skin. The question in this part of the dissertation is:

**2. Are European crime investigative decisions about the evidential value of bitemark-means evidence-based to the standard of Premise 1a of this dissertation?**

This main question will be assessed in light of the conclusions about two related questions. First:

**2a. Were the series of decisions about the evidential value of the bitemark-means in the Norwegian Torgersen-case evidence-based to the standard of Premise 1a. of this dissertation?**

**Chapter 5** introduces the Norwegian Torgersen-case and discusses the relevance of the sources available with respect to answering question 2a. The sources are insufficient with respect to information about the reasoning of the crime-investigators. They are far better with respect to the *written* expert-reports justifying the diagnoses of the bitemark, but still insufficient with respect to information on the expert-statements during their oral testimonies. The bias introduced by letting the information in the written expert-reports represent that of the crime investigators at the time of decisions is discussed and decided to not represent a treat to the purpose of the analysis. A brief introduction to the Norwegian legal system is provided in Appendix 1.

**Chapter 6** analyses the first bitemark-expert's (in 1957/1958) justification for his diagnosis of the bitemark. The information provided in the written report was not sufficient for assessing the expert's conclusion because (1) no information at all was provided for the diagnosis-criterion of time of occurrence of the bitemark and (2) incomplete information was provided for the diagnosis-criterion about the source-object of the bitemark (implicit and ambiguous information on the reference-groups used). The information provided indicates adherence to an inference-procedure labelled "incomplete and open induction". This procedure does not satisfy the standard of Premise 1. The expert's diagnosis of the bitemark may have been correct or it may have been wrong, but the information needed for assessing this, is, as said, either absent or ambiguous. An addendum to the chapter presents the defence counsel's argument that the case qualifies for review. In **Chapter 7** I study the modern bitemark-experts' (in the period between 1997 and 2006, court-appointed as well as party-appointed) justification for their diagnoses. Again and for the same reasons the information provided in the written reports is not sufficient for the diagnoses to qualify as evidence-based according to standard of Premise 1. An addendum to the chapter presents the Norwegian Criminal Cases Review Commission's position on evidence-theoretical issues.

The second question under the main question is:

**2.b. Are bitemark-experts' decisions about hypotheses investigated for more general knowledge-purposes (a) relevant for practical forensic diagnoses and (b) evidence-based to the standard specified in Premise 1?**

In **Chapter 8** I assess this question in light of studies published in scientific journals between January 1976 and December 2008. The procedure

used to identify items is described and assessed (the final collection of papers constituting the basis for the assessment of question 2.b is included in Appendix 3). In the second section of chapter eight I present the inference-procedure recommended by The American Board of Forensic Odontology (ABFO), which is the main authority for forensic bitemark-analysis. This procedure, if followed, is found to provide evidence-based decisions to the standard of Premise 1 and indicates that Premise 1 is neither too strict nor irrelevant to forensic bitemark-diagnoses.

In the third section I present the existing studies of the accuracy and reliability of bitemark-diagnoses. None of the five studies identified was directly relevant to practical diagnostic situations (the AUC's (ROC) were between 0.69 and 0.86). In section four I present the results of the literature-review with respect to question 2b: 7.6 % of the papers identified was found to be both relevant to practical bitemark-diagnosis and evidence-based to the standard of Premise 1. The papers categorized as materially relevant to practical bitemark-diagnosis, were found not to be evidence-based according to the standard of Premise 1 due to absence or ambiguous information — most likely due to adherence to the inference-standard of "incomplete and open induction".

But the 7.6 % evidence-based studies provides poor knowledge-support for practical bitemark-diagnostic purposes: Only partial knowledge exists of the relationship (a) between teeth/mouth-markers and bitemark-markers, (b) between pairs of markers, or (c) between pairs of markers and the background conditions most likely intervening during bitemark-production; and only one study is indirectly relevant to the time-criterion of bitemark-diagnosis. In light of (a) the analytical norms adhered to by bitemark-analysts who have published research relevant for practical diagnosis and (b) the general state of knowledge indicated by this research, the crime-investigator should not expect a bitemark-analyst to be evidence-based to the standard recommended by ABFO (nor to the standard of Premise 1 of this dissertation).

The conclusion to question 2, given the conclusions to questions 2a and 2b, must be that it is more likely than not that European crime investigative decisions about the evidential value of bitemark-means will not be evidence-based to the standard of Premise 1 of this dissertation.

In **Part III** of this dissertation I try to be reconstructive. The question in this part of the dissertation is:

### **A Bayesian theoretical approach to crime investiga-**

tive and forensic bitemark-problems provides decisions which are evidence-based to the standard of Premise 1 of this dissertation: The decision may thus serve the parties' and the public's basic and shared epistemic needs and values. But what about the parties' and the public's contextual/situational and conflicting social and symbolic emotional needs? Does the Bayesian theoretical approach's, by its use of formal logical heuristics, affect the ability to serve these needs — as these become increasingly more prominent during the trial phase of the criminal case process?

In **Chapter 9** I suggest that a subjectivist or personalistic Bayesian Network approach ( $BN_s$ ) is a possible alternative to the existing crime-investigative procedure for determining the basic causal-logical mechanism of a bitemark. The epistemological concepts and technical heuristics of  $BN_s$  is introduced, explained, and specified, and argued to be adequately accounting for the *epistemological* conditions and aims of the crime investigative decision. This chapter may seem superfluous to those naturally inclined to the logic-structural and the reasoning-qualitative aspects of knowledge production. It contains nothing new. However, as I argue in the second part of this dissertation, the relevance of epistemology, logic, and methodology seems to remain at best unclear to a large proportion of legal scholars, crime investigators, and forensic experts. The risk of being met with unconstructive en-block resistance coupled with the poorly developed discourse on epistemological norms and procedures within jurisprudence, crime investigation, and forensic odontology is the reason why I insist on including this chapter: I believe, perhaps naively, that an explicit justification of the connections between the epistemological and the methodological concepts and heuristics will facilitate the necessary transfer to evidence-based crime-investigation. My suggested decision-procedure for bitemark-means may be wrong or ill-suited, but the fact that it is explicitly justified — in contrast to the existing decision-procedure — makes it at least a reference from which to develop better concepts and better procedures.

In **Chapter 10** I proceed to specify the kind of bitemark-problem to be modelled in the terms of Bayesian Decision Theory. The first part specifies the context, the relevant events, the relevant consequences, and the decision-options of the problem. This provides the basis for the expression

of the bitemark-problem as a utility-function. Secondly, the likelihood-ratio is suggested used by the crime investigator as an indicator of the value of the expert-information with respect to the diagnostic criteria involved in the problem. Thirdly, a general likelihood-ratio for the bitemark-problem is suggested and justified, and a general utility-function for the bitemark-problem is specified.

In **Chapter 11** I perform a  $\text{BN}_s$ -analysis of a crime-investigative bitemark-problem approximating that of the Torgersen-case. Borrowing the reality of the case, it will be assumed (a) that four markers were used for the expert-diagnosis of the most likely causal biting-mechanism of the bitemark and that these have certain distributions; (b) that a joint set of both case-particular and expert-knowledge markers was used for the diagnosis of simultaneity between the legal injury and the bitemark and that this has a certain distribution; and (c) that the experts have a certain diagnostic accuracy when using these markers for the two diagnostic purposes. The likelihood-ratio for the problem is calculated and interpreted and I demonstrate how different reference-classes affect the posterior probabilities.

**Chapter 12** concludes this dissertation. The suggested  $\text{BN}_s$ -solution to the crime-investigative bitemark-problem is related to the worries held by opponents to formal approaches to evidence-assessment in the legal context. These worries are concluded to be far less relevant when the  $\text{BN}_s$ -approach is restricted to the decisions at the investigative level. If Premise 2 and Premise 3 are reasonable then the investigative decisions should not under-communicate uncertainty — quite the contrary: Crime-investigative knowledge is then expert-knowledge just like any other expert-knowledge and not only can but also should adopt a methodology which routinely induces assessments of the risks of propagating false beliefs.

The chapter ends by suggesting a basic guideline to crime investigators with a bitemark-problem similar to the one specified in Chapter 11. This guideline specifies the minimum set of questions the crime investigator needs to assess and answer for such problems in order for the decision about basic relevance or evidential value to be evidence-based. The guideline includes the questions needed answered by the bitemark-experts and the medical examiners as well.

With the current state of knowledge of bitemark-production, one should not be surprised that future bitemark-means will tend to be rejected: The markers most often observed are ill defined, their role during bitemark-production is poorly understood, and their discriminatory powers under dif-

ferent conditions have poor independent support in systematic studies or expert-consensus. Given this state of knowledge, the risk of unconstructive expert-battles during the trial-phase will continue to be high. An improvement may take more than a couple of years: The studies for better markers will in itself take time, but this can only happen when the bitemark-experts start to cooperate towards a common set of concepts and, not the least, a common methodology that suits modern forensic needs.

# Part I

## The epistemological and institutional conditions of legal evidence and proof

In order to assess current and alternative epistemological norms and methodological procedures for crime investigative problems one must account for the epistemological as well as institutional conditions, aims, and values of the criminal case process. This is the aim of this first part of this dissertation. The question is:

**What are the epistemological and institutional conditions, aims, and values differentiating inference in the legal context from inference in the scientific context?**

In **Chapter 2** I introduce the concept of evidence and inference/proof, first in the terms of epistemology and methodology and then in the terms of jurisprudence. The history of the legal notions of evidence and proof is presented and a central dimension of conflict or a *jurisprudential foundational problem* is identified.

In **Chapter 3** I present what I believe to be the catalyst of the modern expression of the foundational problem in legal theories of evidence — namely the arrival of the notion of subjective or personalistic probability.

In **Chapter 4** I present the positions held with respect to aspects of the foundational problem and the resistance existing in jurisprudence to formal approaches for assessing evidence is explained.

# Chapter 2

## The discourse on inference, proof, and evidence

In this chapter I will present the conceptual apparatus needed for an interdisciplinary discourse on inference, proof, and evidence. Various disciplines will develop their own terms and it is necessary to identify the common phenomena referred to by these terms. In the first section I will present the basic epistemological position of the dissertation — that of *moderate foundationalism coupled with realism*. In the second section I will present the concepts needed for this dissertation in epistemological terms. In the third section I present the analogue concepts in the historical terms of legal theories on evidence and proof.

### 2.1 Inference and justification — in the terms of epistemology

This dissertation holds the view that all inquiry has a basically similar reasoning structure: The complex methods of science are but amplifications, tailor-made over time to suit the needs arising in a multitude of differently conditioned problem situations. A central claim is that the *purpose* of scientific methods is equal to that of institutional procedures and organizational instructions: To *standardise* performance across decision-makers and particular cases to achieve as many correct decisions as possible (decisions which achieve the aims intended and protect the values aspired) and as few wrong decisions as possible (decisions which fail to achieve the aims intended and

thus harm the values aspired). The more important the aim is and the more complex the problem, the more complex these methods, procedures, or instructions will be. Complexity may be regretted but it is unavoidable — the world *is* complex.

The dissertation thus folds in with the more moderate theories of knowledge and evidence. It is inspired by the writings of Charles S. Peirce, Ian Hacking, David A. Schum, and Susan Haack. Haack's "Critical Common-Sensism" is representative of the position of this dissertation:

"Critical Common-Sensism" acknowledges [...] that there are objective standards of better and worse evidence and of better and worse conducted inquiry, [...] and acknowledges too that observation and theory are inter-dependent, that scientific vocabulary shifts and changes meaning, and that science is a deeply social enterprise [...].

The core standards of good evidence and well-conducted inquiry are not internal to sciences, but common to empirical inquiry of every kind. In judging where science has succeeded and where it has failed, in what areas and at what times it has done better and in what worse, we are appealing to the standards by which we judge the solidity of empirical beliefs, or the rigor and thoroughness of empirical inquiry, generally. Often, to be sure, only a specialist can judge the weight of evidence or the thoroughness of precautions against error, etc; for such judgements require a broad and detailed knowledge of background theory, and a familiarity with technical vocabulary, not easily available to the lay person. Nevertheless, respect for evidence, care in weighing it, and persistence in seeking it out, so far from being exclusively scientific desiderata, are the standards by which we judge all inquirers, detectives, historians, investigative journalists, etc, as well as scientists. In short, the sciences are not epistemologically privileged. (Haack 2003:23)

Moderate theories of knowledge seek to account for the nature of the inferential processes in which one belief is formed on the basis of other beliefs and for the ways in which these processes extends justification and knowledge. At the heart of these theories lies a shared perception of the *architecture* of knowledge: *Truth and meaning* are the purposes of knowledge; *beliefs* are the necessary bricks of knowledge; *justification* being *relevant, reliable, and coherent*, is the necessary cement between the bricks; and our faculties of sensing, reasoning, and emotion are the necessary tools for knowledge. (Haack 2003, p. 23)

But the theories will differ with respect to the weight ascribed to the parts of the architecture: Some scholars, **foundationalists**, hold that the *basic* sources of knowledge is critical: To have knowledge or justified belief at all, you must presuppose that some beliefs are basic by being directly connected

in a *reliable* and *causal* way to its sources through sense-perception, memory, introspection, and reason. Other scholars, **coherentists**, insist that the *cement* of justification is critical: To have knowledge and justified belief at all you need beliefs to connect with each other in a certain manner and according to certain standards required by the more or less contingent context — otherwise the *meaning* of the knowledge is lost to us. A coherentist would of course accept that we need an *epistemic* chain (anchored in basic beliefs or not) in which beliefs are built upon each other, transmitting justification this way, but this transmission cannot happen without a *psychological* and *cognitive* sense of coherence between the beliefs, a coherence which is partly dependent on the situation we are in (the content and our previous knowledge of that content).

The position on these issues in this dissertation is **moderate foundationalism coupled with realism** as it is described by Robert Audi (2003:212-213):

- Knowledge and justified belief about more or less mind-dependent objects, events, phenomena, and processes are possible;
- some beliefs are directly anchored in, and thus traceable to its sources such as sense-perception and reason;
- any belief can at any time and by any person be more or less indirect depending on the context;
- a belief may gain or lose justification;
- a belief may have any content;
- some foundational beliefs may be false, unjustified, or both — experiential sources and reason are less than perfectly reliable.

It cannot and will not be presumed that this position is without problems or that it is better than any other position possible. I shall have to assume that it works at least as well as any other position given the particular purpose of this dissertation.

So, when I claim in this dissertation that crime investigation both can and should be evidence-based by adhering to one identified set of epistemological norms and methodological rules, then I assume the possibility and relevance of moderate foundationalism coupled with realism.

The concept of evidence has always been studied in philosophical discipline of epistemology, aided by psychological theories of cognition, linguistic theories on meaning, and theories of social norms of what knowledge is and

should be. But the issues of interest to philosophers have not always been found equally interesting or relevant to working scientists. The urgency of the academic philosopher is quite different from that of the practicing physician or judge — the philosopher’s constant nagging about order and standards has been as welcome to the practicing scientist as an accountant in a flourishing oil-company. But the increase in knowledge and communication technologies and the tighter budgets have made the resources of epistemology into input-capital in its own right: The result has been the growth of a new evidence-scholarship with a more practically oriented epistemology.

### 2.1.1 Sensing and believing — a practical example

A medical examiner which approaches a body recently brought in for forensic examination will let his eyes run over the whole body to get an initial superficial oversight: Torn clothes, dirt, contusions, bruising, lacerations, and blood may be visible. When attending more thoroughly to one thing at a time, the examiner will perhaps arrive at something on the breast which had been briefly registered: The first impression may have been registered as "irregularity here. Dirt?". Upon the closer inspection it may be reconsidered: "The irregularity is not dirt but bruising and incisions". The first belief was *perceptual* — caused by the *seeing* of an irregularity in the form of a delimited area with an unexpected colour and surface differentiated from the surrounding skin. The second belief, that this was bruising and incisions, stems not from seeing this directly but indirectly, based on *both* the direct belief that here is an irregularity (the *seeing*) and by another indirect belief that this irregularity has properties which looks more like those usually classified as bruising and incisions. The examiner sees this irregularity, recognizing its qualities, comes to believe that it looks like those things called bruising and incisions, and concludes that here is bruising and incision.<sup>1</sup>

The examiner has just performed an *inference* — a kind of reasoning. An inference is an *argument* from one set of propositions or claims — the *premises* to another set of propositions or claims — the *conclusion*. The inference in the example was an inference from the general to the particular for one individual (the thing/phenomenon observed): From *irregularity* to *irregularity in the form of bruising and incision*. But in between there occurred

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<sup>1</sup>This example is originally from Audi (2003: Chapters 1 and 6), but I have taken the liberty to alter it to make it more directly relevant to the dissertation.

another kind of inference as well, that from the particular to the general: The examiner initially labelled this irregularity as dirt — a general class of irregularities with its own qualities — and held this belief a brief moment until returning for closer inspection. But then the examiner reconsiders: If it is dirt, then the specific "dirt"-qualities must exist in this particular irregularity. He or she finds that they do not and concludes that this irregularity is not dirt. By this the examiner moves the irregularity back to the broader class-level — the class of "dirt" was considered premature. That is inference from the particular to the general. A brief digression about generals and particulars is necessary.

We usually think about "particulars", "generals", and "generalization" as being about the number of *individuals* having one property: From "these 20 students are very nervous about the exam?" to "all students are very nervous about the exam". But generalization may just as well be about the number of *properties* held by one individual: From "this irregularity has *depth, width, breadth, colour, external cause, etc.*" to "this irregularity is a *bitemark*"; or from "this real event has the properties *a,b,c, .., and n*" to "this real event is subsumable in the class of events covered by section 192 in the Penal Code". The latter kind is typical to the legal context and is often used to explain why formal approaches to evidence-assessments are not useful for this context. But it matter less whether the generalization is over individuals or properties: Individuals cannot exist without properties and vice versa. Whether one attends to one property for many individuals or many properties for one individual is a practical consequence of the analytical conditions/possibilities and the purpose of the analysis. Some *statistical techniques* are indeed restricted to analytical conditions which allow attention to one/few properties for many individuals, but the *formal epistemological norms* underlying those techniques are not restricted to such conditions. The question of the norms of analysis, their content as well as how situation-dependent they should be, is instead governed by the purpose of the analysis — highly standardized norms being more compatible with positive analysis than normative analysis. As long as the purpose is positive analysis, the condition of having to attend to many properties for one individual is well compatible with highly standardized norms (see further justification for this claim in the section on Premise 3 in Chapter 1). In this dissertation, when concentrating on positive analysis, "generalization" or "subsumption" includes both inference from few to many individuals with respect to one property and inference from few to many properties for one individual.

To conclude this subsection: The examiner thus uses *direct* beliefs based in perception, memory, and reason, *indirect* beliefs derived from these, and *inference* to make a reasoned conclusion about this particular irregularity — a conclusion which can be justified and which can thus constitute justified belief and even knowledge.

### 2.1.2 What is an inferential belief?

The moving from the sense-perception to the belief is an inference (or argument) between generals and particulars. The *concluding* and the *believing* are *mental entities*. These are *properties* of a person's mind or *mental faculties*. The *contents* of concluding and believing are *objects*. These objects are not the property of the person's mind, but can be thought of as *propositions*, *statements*, *claims*, or *hypotheses*. A critical property of these objects is that they can be true or false. (Audi 2006:156-158). Two kinds of entities are thus integrally involved in an inference: (1) The mental *process* of concluding on the basis of believing; and (2) the *propositions* of the believing and the concluding. The propositions identify what is inferred from what. A person, say, the examiner in the above example, might not necessarily express the inferential process and its content in a *language* — he or she might not even be conscious of it. It is just done, naturally. But he or she can express it in the terms of a language, orally or by writing, if required.

The medical examiner thus uses his or her senses, his or her mental faculties or powers, and his or her language when trying to make meaningful, understand, explain, or learn about that which triggered the inference. The process from sensing an irregularity to categorizing it as dirt or bruising is one of giving meaning to or explaining the irregularity. The inference has created *new knowledge*.

Inference is thus a source of justification and knowledge. But it is not a basic source like sense-perception, reason, and emotion. It is a *dependent source*, necessary but not in itself sufficient — it is a device or instrument for *transmitting and extending* justification from one belief to another (Audi 2003:162-165). Only if the examiner is justified in the belief(s) constituting the premises of the argument may the inference justify the belief constituting the conclusion. And, by the kind of moderate foundationalism of this dissertation, the former is justified only if grounded directly or indirectly in a basic source. The knowledge about the irregularity on the skin of the body — that it is a bruising — is *new knowledge*, but it may also be used to solidify

other beliefs by *buttressing* these: Perhaps the examiner suspects (abduces, tentatively believes), due to other circumstances, that the victim's death was caused during a sexual assault — then he or she may use the bruising and it being on the breast as further and strengthening reasons for that suspicion. And both new and buttressed beliefs may be yet further justified by other and *independent* sets of premises: Just having formed the belief that this might possibly be bruising, further justification may be had if a colleague comments that "there is a bruising there". The colleague might be wrong just like the examiner might be wrong, but when two independent sources arrive independently at the same belief it takes a bit more to undermine it.

### 2.1.3 How may inference contribute to justification?

If inference is not a basic source of justification, but a dependent one — *aiding* the transmission of justification — what must exist for it to work as a transmitter? Audi (2003: 164-165) sees two kinds of conditions: First there are the *source conditions* — the beliefs in the premises of a conclusion must be justified in the first place; Secondly, there are the *transmission conditions* — the nature of the *relation* between the premises and the conclusion must be sufficiently sound and strong in some sense.

The examiner in our example may be justified in believing that the irregularity on the breast is bruising. Say that he or she also believes it looks like a human bitemark — a further subclass under the class of bruising and incision. The examiner knows well that he or she cannot just jump to this conclusion — because the transmission is not yet done in "the right way". The bruising and incisions might well be a human bitemark, but he/she might be wrong. And to claim that something is a bitemark when it is not may have serious consequences in the context of the medical examiner. The medical examiner therefore asks if the inference is *sound* enough: "Are the characteristics which made me think of a human bitemark *relevant* and *sufficiently so*?"; "Is this bruising/incisions a true member of the subclass of bruising/incisions we call "human bitemarks"? He/she might recall the case where the skinmark first was diagnosed as a human bitemark, but had to be re-categorized as a mark from a bottle-cap. The question the examiner asks here is if the transmission of justification *can* occur and *how strong* it is.

Audi (2003) suggests that the transmission conditions can be more effectively understood via two basic models of inference: Deduction and induction. These are descriptive *models* of frequently occurring ways in which

inference is actually performed by human beings. And they can be *normative* models — ideals for how inferences *should* be.

I have already said that an inference is an *argument* from the premise-set of propositions to the conclusion-set of propositions. I also said that the *content* of the beliefs are *propositions* of a language. Propositions have the characteristic that they are either true or false. Propositions are claims about how the world is or should be. That is then the object of the proposition (and of the belief). A proposition must minimally contain one subject, a predicate, a copula (a verb-like word linking the subject and the predicate), and a verb. An inference is thus both an argument and its content. The argument and the content are necessarily connected in practice, but we may analytically abstract the *logical* structure of the argument from its *content*. The two models of deduction and induction are models of frequently occurring logical structures. They are the best known and a certain consensus exists about their nature. There are of course other models or types of inference too — *abduction* (inference to the best explanation) being perhaps the more salient type. In this dissertation *abduction* will be reserved for the inferences typically occurring in the initial or the discovery phase of given problems: In this phase the aim is to identify possible explanations and not the testing of carefully formulated hypotheses by carefully designed procedures and standards; the inferences for the detection/discovery-purpose are not subject to strict rules of logic or calculus to allow space for creativity. Abduction is as important to practical problem solving as induction and deduction, but its role during the latter phase of an investigation, where one tests specific hypotheses according to predetermined procedures and standards, is seen to be small.

### **Transmission in a *deductive* argument**

The transmission of justification in a *deductive* argument is necessary and absolute: If the premises are true, then the conclusion is necessarily true too. We may either describe, positively, a given argument as deductive, or we may judge or require it, normatively, to be so.

We may require deductive structure if we need certainty of a particularly safe kind — if we require the argument to be logically *valid* as well as its content being true. Logical validity is only possible if the conclusion is implicit in the premises, already contained in them. In practical reasoning one would rarely require the complete reasoning to have this absolute kind of certainty

(if you do logic or math you might). But deductive kinds of reasoning regularly occur *inside* chains of practical reasoning. And sometimes we might construct an argument as deductive as a heuristic strategy — to disclose or map out the logical consequences of a complex claim. But we would not insist on deductive validity as the final standard for the argument.

### Transmission in an inductive argument

The transmission of justification in an inductive argument is a-necessary and partial. The premises may be certain to some extent and the conclusion will only be certain to some extent as well. A given argument may be described as inductive or we may judge or require it to be inductive. Arguments with premises being more or less certain may be assessed as good or bad by their *soundness*. The most important dimension separating deductive from inductive arguments is thus the certainty dimension.

Now, what are the conditions for transmitting justification through inference? The condition for transmitting justification in a deductive argument is validity: *Only if* all the premises are necessarily true can the truth be transmitted to the conclusion. That is a very strict but also a very clear condition.

The condition for transmitting justification in an inductive argument is soundness: *Only if* all the premises are true to some degree of certainty can the conclusion be true to some degree of certainty. This is not clear at all and admits defeasibility not available in deductive reasoning.

Perhaps soundness means that the premises should be *relevant* to the conclusion? That if the premises were true they would render the conclusion *more certain* than if the premises were false? That would allow the situation in which only a slight change of certainty of the conclusion should be considered sound — which would imply that the *negation* of the conclusion would be only slightly less certain. The condition of relevance seems necessary, but is at best too weak. It could even be seriously misleading: A physician might via one set of information arrive at the conclusion that the patient has a 40% chance to survive the next year, but via a further set of relevant information the physician might have arrived at a much higher (or lower) chance.

Perhaps we should better require that sound induction means taking into account *all* the relevant information? This condition is too strong. All rele-

vant information might not be practically available and we do not even seem to want or need all relevant information: We do not need the fourteenth witness informing the same as the previous thirteen.

Perhaps sound induction should mean the *sufficient* set of relevant information? This might do for an argument having only one step, with one set of premises and one conclusion. But this kind is rare in practical reasoning: Here you have reasoning in several steps, in chains, where one conclusion arrived at becomes a premise in the next, repeatedly. And you might well have sufficient justification at the start of such a chain, but further up justification might potentially decrease to insufficiency. So in a *sound* argument justification is transmitted if you have relevant information, not too little of it, but not too much either — just sufficient for the purpose. This is unfortunately only a bit clearer.

Relevant information is that which is able to change the certainty of the conclusion and a body of information is sufficient when it reaches the threshold of certainty required in a given situation — when it has reached the *standard of proof*. But relevance and sufficiency are not matters of logical structure alone — the *content* or materiality of the issue under determination, the *purposes* of the decision, and the *seriousness* of the consequences determine just as much.

And even if we were able to say something general about what should be sufficiently relevant given these contextual conditions, the situation-specific conditions cannot be accounted for: An argument may be perfectly sound according to logical structure, institutional purpose, and seriousness of the consequences, but still be found unsound due to what we may call *symbolic* factors — factors whose weight in given situations can be more or less unpredictable: Gender and social status are typical such factors.

So, this is as far as we get: An inference can transmit justification

- in deductive arguments, only if the argument is valid — the standard of validity being very precise: If all the premises are true, then the conclusion will be true —
- in induction only if the argument is sound — the standard of soundness being less precise: If all the premises are (a) true to a sufficient degree of certainty, (b) logically relevant to the conclusion, and (c) contextually and situationally relevant to the purpose of the conclusion, then the conclusion will be true to a sufficient degree of certainty.

In the next section the attention is turned to the concept of inference, evidence, and proof in jurisprudence and legal adjudication.

## 2.2 Inference and justification — in the terms of jurisprudence and legal adjudication

In the former section I identified the concepts generally relevant to inference and justification in the terms of epistemology — the discipline which traditionally have studied the foundational issues relevant to truth, knowledge, beliefs, certainty, and justification. Theories of inference and justification developed for the needs and purposes of jurisprudence and practical legal adjudication will mostly agree with the concepts specified in the former section, but use different labels for them. The table below translates the more central ones:

Epistemological term	Term in jurisprudence and practical legal adjudication
Inference	Argument, proof, reasoning
Single chain of argument	Means of evidence
Premise	Premise, Ground
Information	Evidence, reason, information, witness or expert observation, a forensic object itself
Justification	Evidence, relevance, evidential value
Relevance	When a piece of evidence makes a proposition more probable than the proposition would have been if without the evidence
Reliability	When a piece of evidence is what it is believed to be; when an object is authentic; when a witness has normal senses, so that his observation is accurate; When a witness is truthful, wanting to tell the truth
A sound argument	A condition being proved to the standard required by law
Proposition	Proposition, claim, statement

Table 2.1: Corresponding terms in epistemology and jurisprudence

Such theories would also agree on some version of the moderate foundationalism/realism specified at the beginning of the first section of this chapter. Twining (1985) and Anderson, Schum, and Twining (2003) summarizes this basic agreement under the name of "The Rationalist Tradition":

1. Knowledge about particular events is possible
2. Establishing the truth about particular events in issue in a case is a necessary condition for achieving justice in adjudication; incorrect results are one form of injustice.
3. The notions of evidence and proof in adjudication are concerned with rational methods of determining questions of fact; in this context operative distinctions have to be maintained between questions of fact and questions of law, and questions of fact and questions of opinion.
4. The establishment of the truth of alleged facts in adjudication is typically a matter of probabilities falling short of absolute certainty.
5. (a) Judgements about the probabilities of allegations about particular events can and should be reached by reasoning from relevant evidence presented to the decision maker; (b) The characteristic mode of reasoning appropriate to reasoning about probabilities is induction
6. Judgements about probabilities have, generally speaking, to be based on the available stock of knowledge about the common course of events; This is largely a matter of common sense supplemented by specialist scientific or expert knowledge when it is available.
7. The pursuit of truth (i.e. seeking to maximize accuracy in fact-determination) is to be given high, but not necessarily an overriding, priority in relation to other values such as the security of the state, the protection of family relationships, or the curbing of coercive methods of interrogation.
8. One crucial basis for evaluating "fact-finding" institutions, rules and procedures, and techniques is how far they are estimated to maximize accuracy in fact determination - but other criteria such as speed, cheapness, procedural fairness, humanness, public confidence, and the avoidance of vexation for participants are also taken into account
9. The primary role of applied forensic psychology and forensic science is to provide guidance about the reliability of different kinds of evidence and to develop methods and devices for increasing such reliability.

### **2.2.1 A brief history of legal theories of evidence**

The agreement about the basic principles of the The Rationalist Tradition evolved over time since the eighteenth century. In his *Theories of Evidence*.

*Bentham and Wigmore*, (1985), William Twining sees an "old evidence scholarship" in the period between 1750-1800 and 1900:

This first wave of the evidence scholarship in jurisprudence emerged with Lord Chief Baron Gilbert's *Law of Evidence* (1754) and Jeremy Bentham's *Rationale of Judicial Evidence* (1827). They reacted in different ways to the potpourri of precedent ruling in previous cases — rulings governed in an ad hoc fashion by the principle of the *best evidence rule*. Gilbert, a disciple of Locke and his empiricism, tried to impose some order among the precedents to firm up the *best evidence-principle*, but the situation was still rather disordered when Bentham entered the scene in the first decade of the nineteenth century. A strong opponent of rules of evidence, Bentham advocated a return to the "natural" system of free proof as governed by everyday experience and common sense reasoning. He saw the finding of the truth of the facts in issue as necessary for achieving rectitude of decision and his central aim was to develop a design-like procedure which could maximize the overall reliability of adjudicative decisions. Bentham's ideas were too radical for his contemporaries and it seemed easier to support the ideas of Sir James Stephen in his *A digest of the Law of Evidence* (1879): Accepting the wisdom of having at least some rules of evidence, Stephen was the first to suggest one common principle of the rules of evidence — that of *relevance* — based in the logic of J.S. Mill. But it was only the Scottish lawyer William Glassford's *An Essay on the principles of Evidence and Their Application to Subjects of Judicial Inquiry* (1820) which voiced any opposition to the empiricism of Gilbert and Stephen. Nevertheless, Glassford's text signifies a foundational conflict to become much more prominent later: That of a *holistic* versus an *atomistic* approach to evidence and inference with respect to ultimate legal adjudication. The central question in this conflict is: Is the joint collection of evidence more or something else than the mere "sum" of its individual means of evidence?

During the nineteenth century Twining sees the centre of gravity shifting to the United States, where James B. Thayer, by his *A preliminary Treatise on Evidence at the Common Law* (1898), is an most important figure in this old evidence scholarship. Thayer partly rejected Bentham's views by accepting rules of evidence, yet agreed that case-law is without principled reasoning, and he launched *materiality* (not relevance) as the main guiding principle for the rules of evidence. By this it is possible to see Thayer's text as the first to voice another dimension of conflict still alive in the modern evidence discourse in jurisprudence: What are the primary principles for

determining whether a legal proof is sound or not? Should it be the principles of logic — or should it be the principles of materiality of the facts in issue? Thayer of course accepted logic, but could not see any guiding potential for it in a general sense. That role was attributed then to the particular content or materiality of the case and its effect on what could become the facts in issue in a case.

John Henry Wigmore (1863-1943), a student of Thayer, shared the basic acceptance of rules of law, saw materiality as a central guiding principle for determining the soundness of legal proof, but came to focus equally on logical rules as guiding the determination of soundness. Where Thayer provided a rationale for the law of evidence, Wigmore saw this as only part of what he saw to be a broader science of evidence and proof. Wigmore's *The Principles of Judicial Proof* (1937) are foundationally important for the later evidence-scholarship in jurisprudence, and his methodology may be seen as a prototype of the more formal methodologies argued relevant for legal adjudication. His *Chart-method* reflects the recognition that human rational capacities worked well for certain situations and for certain amounts of information, but less well when the amount of information increased and diversified over time. The purpose of the Chart-method was to be an analytical instrument aiding the rational determination of the total effect of a mass of mixed evidence. The Chart-method relies on epistemologically familiar notions: Any narrative of a real life event must be expressed in *propositions* about a few common *types* more or less indirect evidence (objects or testimony), propositions which must *cohere plausibly* via a few common *types* of reasoning processes such as assertion, explanation, denial, rival, corroboration. And uses methodologically familiar instruments: Types of propositions and types of relationships in any given case may be signified symbolically which may juxtapose a complex mass of ideas in a compressed graphical form.

Wigmore's thinking about evidence is important to the modern evidence scholars, not so much by the chart-method per se and certainly despite Wigmore's lack of any explicit epistemological justification or caution about central evidential concepts, such as relevance, reliability, and probability. It is important mainly, I hold, because Wigmore insisted on the existence of a *practically useful* logic. This logic is of course normative, but not in the artificial sense as in the stereotypical old school formal logic for simple inferences.

Wigmore's methodology derived from the observation of actual reasoning

processes and is thus much more suited to the complex multistage inferences we find in real legal trials. This makes Wigmore's notion of relevance, despite (or perhaps because?) it not being anchored in any established epistemological theories: It may be seen to be richer than that the relevance-notion used of the more formally inclined analysts, particularly those adhering to Bayesian theory and methodology. "Bayesians" agree that a notion of probability is necessary for the notion of relevance; that relevance is always conditioned in more or less particularized ways, including the complexly conditioned kind occurring in practical legal adjudication; and that the coherence-component of relevance is and must be coloured by the content of the propositions involved — a content carrying potential for multiple symbolic meanings to different people. But "Bayesians" have not always been able to convincingly explain to legal scholars why and how this is so in their own terms. Wigmore's terms for analysing practical legal inferences thus *complements* the terms of the Bayesians. This, I believe, is why modern scholars such as Schum, Tillers, Twining, and Anderson see Wigmore's *Principles* as such an important source to their own works.

### 2.2.2 Conclusion old scholarship

Twining (1985) sees the first half of the twentieth century as a fallow period for both English and American Evidence theorizing, with Wigmore remaining the more visible scholar. Foundational issues of jurisprudence are signified by the disagreement about which principles can and should govern evidence-assessments - holism vs. atomism and situational coherence vs. "pure" logic. But all in all Twining sees more homogeneity than heterogeneity in the first major wave of the evidence scholarship: A basic agreement about the nature and ends of adjudication, about the possibilities of having knowledge about particular events, and about what is involved in reasoning about disputed questions of fact in forensic contexts.

Twining (1985) notes that this homogeneity (in 1985) was particular to jurisprudence — other disciplines showed much more heterogeneity. Jurisprudence' interest in and theorizing about evidence and proof was constrained to issues relevant to the discourse on the law of evidence and the presumptions were those of an almost nave optimistic rationalism — "remarkably unsceptical" (Twining 1985, p.177). It insisted on a simplistic model of adjudication and litigation where the final adjudicative stage of a trial with a jury represents a rather diversified set of processes — such as the fact-finding/selection

stage during crime investigation, the negotiation-stage before the adjudication, and the sentencing process after the adjudication. The connection to the broader discourse on evidence, inference, and reasoning in other disciplines, such as epistemology or psychology, remained loose and unsystematic. This feature, Twining suggests, may be the reason for the extraordinary isolation of the study of evidence from intellectual developments in other fields during the twentieth century.

So far I have presented the basic concepts and relations relevant to this dissertation's theme of evidence-based crime investigation. But I am not quite ready: I must identify the *modern* conditions for what can be the most appropriate methodologies. This will be the topic of the next two chapters.

# Chapter 3

## The catalyst of the modern discourse on evidence and proof

In this and the next chapter I will review a foundational conflict which has been and still is important to legal theories and practical procedures concerning evidence and proof. The conflict is one between the **protectionists**, who see the institutional and societal values of legal institution as *unique* determinants of legal adjudication — a position implying the rejection of any approaches to problem-solving developed outside the legal context — and the **eclectics**, who do not see the values of the legal institution as essentially different from the values of other institutions — a position recognizing the values attached to truth and certainty (accuracy, precision/unambiguity, objectivity, and impartiality) and accepting the potential suitability of approaches developed for scientific purposes. This conflict rearranged the positions held on the two conflicts mentioned in the previous chapter. A protectionist will resist any formal approach to legal adjudication, but an eclectic may hold either (a) that logical principles (including the content of propositions) alone can and should guide the assessment of the soundness of legal arguments or (b) that logical principles *and* other principles compatible with these can and should guide such assessments. These other principles are various formal principles for accounting for the uncertainty-aspect of inductive arguments — those of probability and utility. An eclectic of kind (b) will be referred to as a **probabilist**.

I will concentrate on the conflict between the protectionists and the probabilists as this best exhibits issues which are irresolvable, yet which must be kept foremost in our minds when studying existing and alternative practical

methodologies for analysing evidence in the legal context: The issues remind us of the values which are at stake in legal adjudication. I will expose the arguments of the conflict as represented in a series of seminal papers from the late 1960's and early 1970's and argue that the conflict was revitalized at the turn of our century due to an increased attention to the appropriateness of the current epistemological norms and methodological rules of forensic science.

But in order to assess the strength and weaknesses of the arguments of these papers, it is necessary to have the conceptual apparatus of the probabilists clear in mind. In this chapter I will therefore present this in the terms of Leonard J. Savage, in his *The Foundations of Statistics* from 1954. The arguments directly relevant to the legal foundational conflict are treated in the next chapter.

### **3.1 The catalyst of the modern discourse on legal evidence and proof**

It may be argued that the catalyst of the modern discourse on legal proof and evidence was the development of an alternative interpretation of the notion of probability: That probability is a measure of the *confidence* or the *degree of belief* a person has in the truth of a given proposition in light of a given set of knowledge.

The ruling interpretation in Savage's time was that probability is a measure of a property of the world, independent of human perception — of phenomena's tendency to occur together according to laws of nature. This *physical/objectivist* interpretation did not make much sense to legal adjudication. The objectivist interpretation presupposes symmetries of processes and outcomes over repeated independent trials under similar conditions — while the processes relevant to legal adjudication is highly conditioned and unrepeatable. The development of the *epistemic/subjectivist* interpretation may be said to be a response to the needs of analysts being in a different place in the *investigative loop*.

In the previous chapter I said that a practical inference will involve generalization (from few to many individuals with respect to one property or from few to many properties with respect to one individual) and standards or norms for this generalization (deduction and induction). A scientist will

typically ask: "What is the probability of this sample if (a) the population or causal mechanism can be represented by this probability-model and (b) the individuals of the sample are randomly selected?" Here the analyst has had the time to study the phenomenon; specify the conditions and choose/fit an appropriate model; select the sample-individuals through a mechanism ensuring independence between them; perform the experiment under controlled conditions; and assess whether the results of the experiment are probable or not, conditional on the truth/falsity of the model assumed. The assumptions about the population and the deliberate design of the conditioning of the individuals allow more arguments of the deductive kind than the inductive kind.

An analyst like the medical examiner in the previous chapter will ask a different question: "What is the probability of this suggested causal mechanism if I observe these properties/characteristics of individuals that are *not* randomly selected?" Here the analyst is not in a position to control the conditions of the observations, repeat the process, or strategically ensure independence between the observations. The large number of possible causal mechanisms of these observations allows for fewer arguments of the deductive kind than the inductive kind.

The typical scientist can start at the "top", with the population, the causal mechanism, or the general, and deduce the effects or observations; the medical examiner must start at the "bottom", with the effects or the observations, first *abduce* (suggest/suspect) a set of possible causal mechanisms, and then induce (select via sound argument) the one most likely.

The physical/objectivist interpretation of probability is more suited to the kind of questions asked of the typical scientist. The development of the epistemic/subjectivist interpretation was a response to the analysts who needed to account for uncertainty, but were prevented from using the analytical properties achieved by random sampling and assumed or known conditioning. The legitimization of canons of inductive reasoning coupled with an epistemic/subjective interpretation of probability led to analytical techniques enabling the assessment of *inverse probability* — in turn enabling the estimation of the probability that an identified mechanism is the source of a given set of observations. This appeared much more meaningful to legal scholars with issues of accuracy in practical legal contexts.

Several scholars of probability and statistics were involved in developing this interpretation of probability: D. Wrinch and H. Jeffreys (1919, 1921, 1923), H. Jeffreys (1931, 1939), J. M. Keynes (1921), F. P. Ramsey (1926),

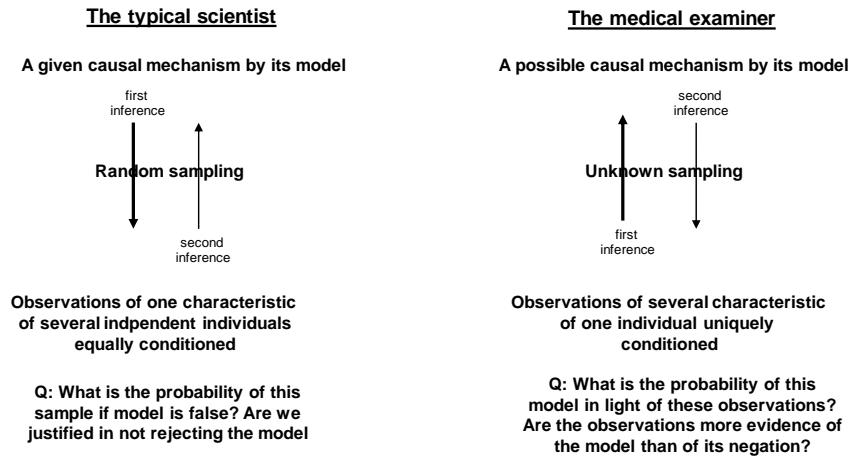


Figure 3.1: Being in different places in the investigative loop. A given causal mechanism or model is here separate from a possible causal mechanism or model by being better justified in terms of having "survived" more selection rounds from the original and wider space of possible causal mechanism/models

B. de Finetti, (1931), R. Carnap (1950), and L. J. Savage (1954) are some of the early contributors. Each had their own interpretation of the logic-probability relationship, but I will let Leonard J. Savage's proposal in his *The Foundations of Statistics* from 1954 (Dover edition 1972) represent the interpretation relevant to the foundational conflicts discussed in this section — the strand focusing on the probability aspects.

## 3.2 Probability: A suitable means towards sound practical arguments?

Savage (1954/1972) was primarily occupied with the interpretation of probability in statistics but his main question was important to legal scholars as well:

Reasoning is commonly associated with logic, but it is obvious, as many have pointed out, that the implications of what is ordinarily called logic are meager indeed when uncertainty is to be faced. It has therefore often been asked whether logic cannot be extended, by principles as acceptable as those of logic itself, to bear more fully on uncertainty. (Savage (1954/1972:6-7)

Savage suggested that these principles could be those of probability. It is important to stress here at the beginning that Savage's theory is a *normative* theory: It suggests logic-analogous standards for reasoning when having to make decisions in situations where there is uncertainty and where the consequences of these decisions are serious. Humans must of course be able to actually adhere to the criteria, but they may, like other ideals, not always correspond to actual reasoning practices. The rationale of Savage's theory was, as for any set of norms or procedures, to aid in achieving aims and protecting values or help avoiding undermining these. The presumption is thus that human beings have aims and values which are sought achieved and maintained through decisions and actions. It is therefore important to ensure that decisions or actions are *not* such that they prevent us from achieving these aims and values. Like Wigmore, Savage recognized that normal human beings are imperfectly able to account for all relevant factors and concerns in given decision-situations. His theory presumes further that human beings are able to reason according to principles. Principles are either known and explicable, such as those of logic, probability, and preference, or unknown and implicit, such as those from psychological, religious, and social needs. Each kind of reasoning is equally important and both will be simultaneously present. Savage's theory is normative, but *not* concerning what should in general be the correct mix of these kinds: He asks instead what can and should be the meaning and content of those principles we *can* explicate when it is agreed that such principles are necessary to avoid undermining given aims and values. Savage, I believe, did not imply that implicit principles are invalid or unsound. These are both operating and useful but analytically

suspended for the purpose of analysing principles we do have agreed concepts for.

### 3.2.1 Three important premises

A first premise of Savage's theory is that it is an effort to answer the needs of the person or *decision-maker* who

- is concerned about a specific phenomenon and its properties because he/she wants to achieve specific aims;
- knows that only one state can be true for the phenomenon but has only partial information about it;
- is uncertain whether this or that state of the world is the correct one;
- knows that this uncertainty can affect the possibility of achieving the aims — that an incorrect decision will, over time, disable the achievement of aims or have unwanted consequences; and
- *has to make a decision.*

A second basic premise of Savage's theory is that descriptions of reality and its possibilities should be structured according to an algebra in which each event has the same logical status. The justification is that this enables the use of standard logical rules for construction and deconstruction of complex events. Savage's theory presumes Boolean algebra and defines events, states, and the basic rules for relating them in the following way (Savage 1954/1972:11):

Term ( <i>Basic terms</i> )	Definition
<b>set</b> $A, B, C, \dots$ $s, s', s''$ $S$ $0$	event generic symbols for events generic symbols for states the universal event the vacuous event
<i>(Relations)</i>	
$s \in A$ .	$s$ is an element of $A$ , i.e., a state in $A$ .
$A \subset B$ (or $B \supset A$ ).	$A$ is contained in $B$ , i.e., every element of $A$ is an element of $B$ .
$A = B$	$A$ equals $B$ , i.e., $A$ is the same set as $B$ , i.e., $A$ and $B$ have exactly the same elements.
<i>(Constructs)</i>	
the <b>complement</b> of $A$ with respect to $S$	those elements of $S$ that are not in $A$ .
$\neg A$	the complement of $A$ with respect to $S$ .
the <b>union</b> of the $A_i$ 's	those elements of $S$ that are elements of at least one of the sets $A_1, A_2$ , etc.
$\bigcup_i A_i$	the union of the $A_i$ 's.
$A \cup B$	the union of $A$ and $B$ , i.e., those elements of $S$ that are elements of $A$ or $B$ (possibly both).
the <b>intersection</b> of the $A_i$ 's	those elements of $S$ that are elements of each the sets $A_1, A_2$ , etc.
$\bigcap_i A_i$	the intersection of the $A_i$ 's
$A \cap B$	the intersection of $A$ and $B$ , i.e., those elements of $S$ that are elements of both $A$ and $B$

This set of rules constitute a *logical heuristic*, a central or basic instrument for protecting certain epistemic norms or values with respect to what it means to have valid and sound reasoning. This logical heuristic is a *premise* for all formal or statistical inference. That it is the logical heuristic which conditions statistical inference and not statistical heuristics which condition logical inference seems to be a point which has been under-communicated to some of the opponents of formal approaches to legal adjudication.

A third premise of Savages theory is the perception of a human *act* and its *consequences*: An act is a decision to choose to do something — intending to make a change, to bring about certain consequences; A consequence is

anything happening to a person as the result of an act. A consequence may be more or less good and may be in terms of money, things, status, wellbeing, health, truth, justice — whatever a person or a group of persons wants and dislikes losing. First Savage's denotation:

**F** denotes a set of acts;

**f, g, h, ...** denotes individual acts;

*F* denote a set of consequences;

*f, g, h, ...* denotes individual consequences;

*f(s)* denotes the act as a function attaching the consequence *f* to the state *s*. (Savage 1954/1972: 13-15)

Savage (1954/1972) suggests that if you have to make a decision and have specific intentions with that decision, but are uncertain about the true state of the world, you should not only account for the possible states, but for the consequences implied when choosing one of these states. How should the decision-maker who has to decide, but is uncertain, proceed? How can he/she more often than not achieve the aims intended by the decisions? Are there principles available which could be followed? Savage (1954/1972) suggests two sets of such principles.

### 3.2.2 Qualitative principles

#### a. Simple ordering of preferences among acts:

A first set of constraints concerns the *relationship* between the *preferences* among a set of acts and their consequences. If the aims are important and affected by the decision, the decision-maker should *rank* or *order* the acts according to his/her (own or instructed) preferences among the possible consequences of each possible act — and this ordering should be *simple* in order to preserve the *coherency* of the decision:

Let the relation  $\leq$  be a simple ordering among acts and let **F** be a *finite* set of acts (so that the structure of algebra is imposed):

- (a) If there exist  $\mathbf{f}$ ,  $\mathbf{h}$ , and  $\mathbf{g}$  in  $\mathbf{F}$  then the relation  $\mathbf{f} \leq \mathbf{g} \leq \mathbf{h}$  should apply to all  $\mathbf{g}$  in  $\mathbf{F}$ . This basic *coherence principle* is usually referred to as the *transitivity principle*: If you find that among acts  $\mathbf{f}$ ,  $\mathbf{g}$ , and  $\mathbf{h}$  you do not prefer  $\mathbf{f}$  to  $\mathbf{g}$  and do not prefer  $\mathbf{g}$  to  $\mathbf{h}$ , then it is not rational, i.e., coherent, to simultaneously not prefer  $\mathbf{h}$  to  $\mathbf{f}$ .
- (b) If  $B_i$  is a partition of  $B$ , and  $\mathbf{f} \leq \mathbf{g}$  given  $B_i$  for each  $i$ , then  $\mathbf{f} \leq \mathbf{g}$  given  $B$ . If in addition  $\mathbf{f} < \mathbf{g}$  given  $B_j$  for at least one  $j$ ,  $\mathbf{f} < \mathbf{g}$  given  $B$ . This second basic principle is usually referred to as the consistency principle: If your preference has an order which you know is unaffected by an uncertain event, your order should not change when you come to know the actual state of that event:
- (c) If  $B_i$  is a partition of  $B$ ; and if (for all  $i$  and  $s$ )  $f_i \leq g_i$ ,  $f(s) = f_i$ , and  $g(s) = g_i$  when  $s \in B_i$ ; then  $\mathbf{f} \leq \mathbf{g}$  given  $B$ . If, in addition,  $f_j < g_j$  for some  $j$  for which  $B_j$  is not null, then  $\mathbf{f} < \mathbf{g}$  given  $B$ . This third basic principle concerns the consequences of the actions and is derived from the two above. It states that if several people agree in their preferences among consequences, then they must also agree on in their preferences among certain acts.

### b. Simple ordering of the degrees of beliefs about uncertain events

A second set of constraints or criteria concerns the *relationship* between the *uncertainties* of a person's beliefs about the occurrence of relevant events. An action will be considered as a possible decision if the action is believed to bring about a specified aim. But if the events relevant to the decision have occurred or will occur only to some degree of certainty, the actual realization of those aims will depend on the occurrence/non-occurrence of the event.

Savage (1954/1972) holds that a person's degree of belief that a relevant event has/will occur can be expressed in terms of probability: A degree of belief in an event is informed, basically, in an epistemic and cognitive process in which the person evaluates different "models" of the situation for which he or she needs the probability. Arguing by a betting-analogy (see addendum to this chapter) Savage (1954/1972) holds that the person chooses the degree which best fits the conditioned situation and suggests the following:

A relation  $\leq \cdot$  between events is a **qualitative probability**; if and only if, for all events  $B, C, D$ ,

1.  $\leq \cdot$  is a simple ordering,
2.  $B \leq \cdot C$ , if and only if  $B \cup D \leq \cdot C \cup D$ , provided  $B \cap D = B \cap D = 0$ ,
3.  $0 \leq \cdot B, 0 < \cdot S$ .

[. . .]

**THEOREM** [...] The relation  $\leq$  as applied to events is a qualitative probability.

(Savage 1954/1972, p. 31)

### 3.2.3 Quantification of degrees of belief and consequences

#### a. From qualitative to quantitative probability

Qualitative probability can be connected to quantitative probability or a *probability measure*. Savage first defined a probability measure:

A **probability measure** on a set  $S$  is a function  $P(B)$  attaching a real number to each  $B \subset S$  such that;

1.  $P(B) \geq 0$  for every  $B$ ;
2. If  $B \cap C = \emptyset$ ,  $P(B \cup C) = P(B) + P(C)$ ;
3.  $P(S) = 1$ .

(Savage 1954/1972:33)

Then Savage identified the condition for connecting the qualitative probability,  $\leq \cdot$ , with the probability measure  $P$ :

If  $S$  carries a probability measure  $P$  and a qualitative probability  $\leq \cdot$  such that, for every  $B, C$ ,  $P(B) \leq P(C)$ , if and only if  $B \leq \cdot C$ ; then  $P$  (**strictly**) **agrees** with  $\leq \cdot$ . If  $B \leq \cdot C$  implies  $P(B) \leq P(C)$ , then  $P$  **almost agrees** with  $\leq \cdot$ . [...] [I]f  $P$  strictly agrees with  $\leq \cdot$  then knowledge of  $P$  implies knowledge of  $\leq \cdot$ . (Savage 1954/1972:34)

Given that certain properties hold for  $S$ , Savage suggested the following criteria concerning the uncertainty relations among a person's beliefs about the occurrence of relevant events:

**Postulate 6'** If  $B < C$ , there exist a partition of  $S$  the union of each element of which  $B$  is less probable than  $C$ .

**Postulate 6** If  $\mathbf{g} < \mathbf{h}$  and  $f$  is any consequence; then there exists a partition of  $S$  such that, if  $\mathbf{g}$  and  $\mathbf{h}$  is so modified on any one element of the partition as to take the value  $f$  at every  $s$  there, other values being undisturbed; then the modified  $\mathbf{g}$  remains less than  $\mathbf{h}$ , or  $\mathbf{g}$  remains less than the modified  $\mathbf{h}$ , as the case may require. (Savage 1954/1972:38-39)

Savage argued that the qualitative relation  $\leq \cdot$  also applies to conditional events:

Theorem [5]1 If  $\leq \cdot$  is a qualitative probability, then so is  $\leq \cdot$  given  $D$ . [...] for any  $D$  that is not null there exists [...] one and only one probability measure  $P(B | D)$  the **(conditional) probability of  $B$  given  $D$**  that almost agrees with  $\leq \cdot$ .

$$P(B | D) = P(B \cap D) / P(D).$$

(Savage 1954/1972:43-44)

This can be interpreted as the probability a person attaches to the event  $B$  after having observed or assumed  $D$  — and can be further interpreted as gaining knowledge about  $B$  when experiencing  $D$ .

Savage's theory was a suggested solution for decision-situations in which the decision-maker had to choose the most probable among alternative mechanisms conditional on a set of uniquely conditioned information. The decision-maker here needs a "reverse" rule for conditional probability. If  $C$  and  $B$  are not null and relevant to each other and  $B_j$ , which in turn is a partition of  $S$ , the partition formula can be expressed as follows:

$$P(C) = \sum_j P(C | B_j) P(B_j).$$

From this we may derive the instrument for "inverse" probability, the so-called **Bayes' rule or theorem**:

$$P(B_i | C) = \frac{P(C | B_i) P(B_i)}{P(C)} = \frac{P(C | B_i) P(B_i)}{\sum_j P(C | B_j) P(B_j)}$$

The fact that

$$\frac{P(B | C)}{P(B)} = \frac{P(C | B)}{P(C)} = \frac{P(B \cap C)}{P(B)P(C)}$$

can be given the following interpretation: Knowledge of  $C$  modifies the probability of  $B$  by the same factor by which knowledge of  $B$  modifies the probability of  $C$ . If the need of the inquiry is to establish the effect of available information on the probability of a hypothesis you should establish the probability of the information conditional on the hypothesis, account for the probability of the hypothesis *before* this information and the probability of the information. This will establish the probability of the hypothesis conditional on the information and provide the effect of observing this information.

The concepts of a **random variable**, a **probability space**, and the **expected value** will be presented here as they are needed later. In the terms of Savage(1954/1972:45-46):

**A random variable** is a function  $\mathbf{x}$  attaching a value  $x(s)$  in some set  $X$  to every  $s$  in  $S$  on which a probability measure  $P$  is defined (if  $\mathbf{x}$  is measurable);

**A probability space** is such an  $S$  together with the measure  $P$ .

**The expected value** of a finitely additive real random variable  $\mathbf{x}$  with a probability distribution  $P(x)$  is a function,  $E(x)$ , attaching a real number to  $\mathbf{x}$ :  $\sum_x xP(x)$ . It may also be expressed as the integral of  $\mathbf{x}$  over  $S$ :  $\int x(s)dP(s)$ . (Savage 1954/1972:43-44)

### b. From qualitative to quantitative consequences

What remains of Savage theory is his argument (a) that the qualitative preference among acts in terms of the consequences also may be connected to a quantitative preference, or a measure of the *value* or *utility* of the acts in light of the consequences and (b) that the *expected utility* of the acts in a decision problem should guide the decision-maker with respect to what is the best act to choose.

Constraining Savage's argument to acts for which there exists partitions  $B_i$  of  $S$  such that  $P(B_i) = \rho_i$  and  $f(s) = f_i$  for  $s \in B_i$ : For these acts (a)

the  $f_i$ 's are a finite sequence of consequences (not necessarily distinct), (b) the  $\rho_i$ 's are a corresponding sequence of non-negative real numbers such that  $\sum_i \rho_i = 1$ , (c) there is always at least one element, and (d) all elements of a given decision-problem are equivalent:

If the events  $B_i$  of a partition have the probabilities  $\rho_i$  and if the act  $\mathbf{f}$  is such that the consequences  $f_i$  will befall the person in case  $B_i$  occurs, then the value of  $f$  is independent of how the partition  $B_i$  is chosen. (Savage 1954/1972:71)

Savage defines utility for this class of acts:

A **utility** is a function  $U$  associating real numbers with consequences in such a way that, if  $[\mathbf{f}] = \sum \rho_i f_i$  and  $[\mathbf{g}] = \sum \sigma_i g_i$ ; then  $[\mathbf{f}] \leq [\mathbf{g}]$ , if and only if  $\sum \rho_i U(f_i) \leq \sum \sigma_i U(g_i)$ . Writing  $U[[\mathbf{f}]]$  for  $\sum \rho_i U(f_i)$ , the condition takes the form  $U[[\mathbf{f}]] \leq U[[\mathbf{g}]]$ . [...] it is convenient to understand that, for an act  $\mathbf{f}$ ,

$$U[\mathbf{f}] = E(U(\mathbf{f})).$$

(Savage 1954/1972:73)

So, the preferences among the acts in terms of their consequences should thus first be ensured ordered according to *simple orderings*,  $\leq$ . This set of constraints couples then with the constraints given by the representing of the values of the consequences by a utility function,  $U$ .

Savage summarizes his theory of preference for (bounded) acts as follows:

[A]n act  $[\mathbf{f}]$  will be understood to be a real-valued random variable. [...]:

**R**  $\mathbf{f} \leq \mathbf{g}$  given  $B$ , if and only if  $P(B) = 0$ , or  $E(\mathbf{f} - \mathbf{g} \mid B) \leq 0$ .

If a person is free to decide among a set of  $\mathbf{F}$  of acts, he will presumably choose one the expectation of which is  $v\mathbf{F}$ , where

$$v(\mathbf{F}) = \sup_{\mathbf{f} \in \mathbf{F}} E(\mathbf{f})$$

provided that such a one exists. [”sup” (”supremum”) refers to the least upper bound value] (Savage 1954/1972:80-82)

This ends the specification of the two main sets of criteria Savage (1954/1972) argues should be respected or imposed on decision-makers needing to be coherent when deciding between alternative acts involving uncertain events and consequences to specified aims and values.

### 3.3 Conclusion

The theory of Savage (1954/1972) was intended for persons, *decision-makers*, who have to make a decision, who have to achieve certain specified aims and avoid certain others, but who were uncertain whether the events in issue had occurred (or would occur): There exist principles of action this person can follow to ensure that choices more often bring about the intended consequences than not. These principles are anchored in generally accepted principles of logic: A real — and imperfect — decision-maker *should ensure*

1. that the preferences among the acts in terms of their consequences are ordered according to *simple orderings*,  $\leq$  — the values of which can and should be represented by a utility function,  $U$ , and
2. that the degrees of belief about uncertain events are ordered according to simple orderings,  $\leq$ , as well — the degrees of which can and should be represented by a probability function,  $P$ ,

in order to coherently arrive at the act with the greatest expected utility with respect to identified consequences and events. By these criteria, Savage argued, the decision-maker has a justified procedure by which to avoid undermining aims and values identified to be important.

It is the need to structure the events of a decision-problem's according to an algebra which is to become the central problem to practical legal adjudication. This structuring forces about equal attention to both the suspected and the alternative hypotheses — an attention which, particularly in cases where the evidence balances on the standard of proof, threatens an aim which is not relevant to the typical scientist: At the end of the trial-phase, a legal decision about responsibility and degree of sanction needs to under-communicate uncertainty to achieve the parties and the public's accept and abidance by that decision. In the next chapter I will substantiate how this problem materializes in the modern legal discourse on evidence and proof.

## ADDENDUM

### Personal probability: simple ordering of degrees of beliefs in events

Savage (1954/1972) holds that a person's degree of belief that a relevant event has/will occur can be expressed in terms of probability: A degree of belief in an event is informed, basically, in an epistemic and cognitive process in which the person evaluates different "models" of the situation for which he or she needs the probability. Savage (1954/1972) holds that the person chooses the degree which best fits the conditioned situation and postulates the following:

To offer a *prize* in case  $A$  obtains means to make available to the person an act  $\mathbf{f}_A$  such that

$$\begin{aligned} f_A(s) &= f & \text{for } s \in A \\ f_A(s) &= f' & \text{for } s \in \neg A, \end{aligned}$$

where  $f' < f$ . The assumption that on which of two events the person will choose to stake a prize does not depend on the prize itself is expressed by the following postulate:

P4 If  $f, f', g, g', A, B, f_A, f_B, g_A, g_B$  are such that

1.  $f' < f, \quad g' < g;$
- 2a.  $f_A(s) = f, \quad g_A(s) = g \quad \text{for } s \in A,$   
 $f_A(s) = f', \quad g_A(s) = g' \quad \text{for } s \in \neg A,$
- 2b.  $f_B(s) = f, \quad g_B(s) = g \quad \text{for } s \in B,$   
 $f_B(s) = f', \quad g_B(s) = g' \quad \text{for } s \in \neg B,$
3.  $\mathbf{f}_A \leq \mathbf{f}_B;$

then  $\mathbf{g}_A \leq \mathbf{g}_B$ .

In the light of P4 it will be said that  $A$  is **not more probable** than  $B$ , abbreviated  $A \leq B$ ; if and only if when  $f' < f$  and  $\mathbf{f}_A, \mathbf{f}_B$  are such that

$$\begin{aligned} f_A(s) &= f & \text{for } s \in A, & f_A(s) = f' & \text{for } s \in \neg A, \\ f_B(s) &= f & \text{for } s \in B, & f_B(s) = f' & \text{for } s \in \neg B; \end{aligned}$$

then  $\mathbf{f}_A \leq \mathbf{f}_B$ .

[...]

I therefore propose the following postulate:

P5 There is at least one pair of consequences  $f, f'$  such that  $f < f'$ .

[...]

A relation  $\leq \cdot$  between events is a **qualitative probability**; if and only if, for all events  $B, C, D$ ,

1.  $\leq \cdot$  is a simple ordering,
2.  $B \leq \cdot C$ , if and only if  $B \cup D \leq \cdot C \cup D$ , provided  $B \cap D = B \cap D = 0$ ,
3.  $0 \leq \cdot B$ ,  $0 < \cdot S$ .

[...]

THEOREM [...] The relation  $\leq$  as applied to events is a qualitative probability.

(Savage 1954/1972, p. 31)

# Chapter 4

## Formal approaches to evidence-assessments in legal adjudication?

Theories such as that of Savage (1954/1972) offered principles of reasoning to legal scholars who worried about the values associated with truth- and certainty-aspects of legal assessment of evidence. But other legal scholars, those viewing the legal institution as having a unique role in society, saw the formal basis of those theories as a threat to the filling of that role. In this chapter the attention will be on the development of the modern jurisprudential discourse — expressed in the discourse among the **probabilists** and the **protectionists**. This *foundational* conflict is a persistent one and therefore relevant to this dissertation (the concept of evidence is intrinsically connected to foundational issues in any discipline): any constructive effort to develop a notion of evidence-based decisions within the legal sector must therefore acknowledge the concerns which will be provoked.

The first legal scholars to advocate more formal approaches to practical legal assessments of evidence and proof were John Kaplan (1965, 1968), Alan D. Cullison (1969), and Finkelstein and Fairly (1970). In this dissertation Alan D. Cullison's *Probability analysis of Judicial Fact-Finding. A preliminary outline of the subjective approach* from 1969 will represent the **probabilists**. It is chosen because it (a) is the only text which identifies the epistemological connection between its suggested methodology and the foundational issues of legal adjudication and (b) illustrates a critical aspect of the foundational conflict, namely the different interpretations of the pur-

poses of the legal standard of proof. The **protectionists** will be represented by Laurence H. Tribe's seminal paper *Trial by Mathematics: Precision and Ritual in the Legal Process* (1971). This is chosen because it is the only text which directly and in a constructive way counters the probabilists's arguments. I hold that Tribe (1971) still is, in 2011, among the better texts for understanding the foundational conflict concerning legal assessment of evidence.

The first section explicates the **probabilists'** position in the terms of Cullison (1969); the second section explicates the **protectionists'** arguments in the terms of Tribe (1971); and, lastly, I will present perspectives for partitioning the different kinds of decision-situations involved in the processing of a legal case. The argument of this chapter is (a) that the resistance to formal approaches during the *trial-phase* assessments of evidence is well founded and may not be expected to diminish, but (b) that the resistance to such approaches during the *investigative phase* is not well founded and may even harm the ultimate aims and values of the criminal case process.

## 4.1 Cullison (1969): A probability model of the trial process

Legal scholars of proof and evidence have of course noted the peculiar reasoning problems associated with the need to decide on the basis of strongly conditioned information. In the late 60's Wigmore (1937) was still the main text offering an analytical procedure for such situations (Twining 1986), but his chart method seemed anachronistic and did not account in any principled manner for the uncertainty aspects. The theories of epistemic/subjective probability and the instrument of inverse probability, coupled with the theory of expected utility, thus filled a need felt by a part of the legal community.

Noting that the fact-finding of lawsuits is oriented towards human action tinged with values and that the "facts" of legal assessments are inevitably uncertain, Cullison (1969) could not but see that probability-theory had much to offer and that the subjective theory of probability was an appropriate approach. He thus wanted to outline a probabilistic model for describing the fact-finding process.

The basic decision-problem in legal adjudication, Cullison (1969) argues, is that of choosing the correct of two possible alternatives —guilt and not

guilt in criminal cases (and liable or not liable in civil cases) — in light of the presented evidence and the requirement that the decision of guilt cannot be taken unless proven beyond a specified standard. The intention of the latter is to achieve specified aims and values and to avoid specified costs or losses: The aims in legal decisions are to decide guilty when truly guilty and to decide not guilty when truly not guilty; and the costs or losses to be avoided are those of deciding guilty when truly not guilty and deciding not guilty when truly guilty. In each individual legal decision there are thus four possible outcomes (Cullison, 1969, p. 569):

1. Decide guilty when truly guilty — denoted by  $(c | g)$
2. Decide not guilty when truly not guilty — denoted by  $(\neg c | \neg g)$
3. Decide guilty when truly not guilty — denoted by  $(c | \neg g)$
4. Decide not guilty when truly guilty — denoted by  $(\neg c | g)$

These aims and costs connect with institutional values — that a legal adjudication should avoid ending up convicting an innocent or acquitting a guilty — which in turn connect to social values of justice — that an accused is to be presumed innocent until guilt is proven beyond a certain standard. If concentrating on crime cases, the following order of preference is suggested:

$$(c | \neg g) < (\neg c | g) < (\neg c | \neg g) \leq (c | g).$$

Letting  $P(g)$  and  $P(\neg g)$  denote the probability of guilt and not guilt respectively, Cullison (1969) suggests that the desirability, denoted by  $D$ , of deciding "guilt" or "acquittal" in the terms of decision-theory should be:

$$D(c) = P(g)D(c | g) + P(\neg g)D(c | \neg g)$$

and

$$D(\neg c) = P(g)D(\neg c | g) + P(\neg g)D(\neg c | \neg g)$$

respectively.

The usual legal standard of proof in crime cases is that guilt must be proven "beyond reasonable doubt": When the fact-finders' belief in guilt,  $P(g)$ , is not beyond reasonable doubt, the utility of acquitting the defendant is greater than the utility of convicting; when beyond the standard the reverse

is the case; and when only barely convinced that the standard is met, the two alternative decisions should have equal utility. So, the minimum probability of guilt needed for conviction occurs when the utility of deciding "guilty" equals the utility of deciding "acquit":

$$\begin{aligned}
D(c) &= D(\neg c) \\
&= P(g)D(c | g) + P(\neg g)D(c | \neg g) \\
&= P(g)D(\neg c | g) + P(\neg g)D(\neg c | \neg g) \frac{P(g)}{P(\neg g)} \\
&= \frac{D(\neg c | \neg g) - D(c | \neg g)}{D(c | g) - D(\neg c | g)}.
\end{aligned}$$

(Cullison, 1969, p. 569)

The ratio  $\frac{P(g)}{P(\neg g)}$  equals the ratio of two differences: That between the utility of acquitting an innocent and the utility of convicting an innocent, and that between the utility of convicting a guilty and the utility of acquitting a guilty. The denominator is the amount by which the utility of convicting a guilty exceeds that of acquitting him and the numerator the amount by which the utility of acquitting an innocent exceeds that of convicting him. According to the preference-order both differences should be positive and as large as possible (the principle of maximizing expected utility). The principle may be restated as the principle of minimizing the costs of deciding incorrectly by taking the negatives of the differences — denoting the cost of incorrectly convicting an innocent by  $D(I)$  and the cost of incorrectly acquitting the guilty as  $(DII)$ :

$$\begin{aligned}
D(I) &= -[D(\neg c | \neg g) - D(c | \neg g)] = D(c | \neg g) - D(\neg c | \neg g); \\
D(II) &= -[D(c | g) - D(\neg c | g)] = D(\neg c | g) - D(c | g).
\end{aligned}$$

(Cullison, 1969, p. 569)

Substituting we get (Cullison, 1969, p. 569):

$$\frac{P(g)}{P(\neg g)} = \frac{DI}{D(II)},$$

and since  $P(\neg g) = 1 - P(g)$ , we get

$$P(g) = \frac{1}{1 + D(II)/D(I)}.$$

The minimum probability needed for conviction should be large if a mistaken acquittal is more desirable (less costly) than a mistaken conviction; and small if a mistaken conviction is less serious than a mistaken acquittal. If the aim is to minimize, over time, *both* kinds of error (as is normally the aim in civil cases) the probability standard of proof should be set to 0.5. But if the aim is to minimize the risk of wrongly convicting an innocent (the norm in criminal cases) then the probability of guilt should be increased to above 0.5.

Cullison (1969) believes this approach to be sound epistemologically, but also legally: It admits the flexibility needed in legal adjudication of real cases where the specifications  $D(c | g)$  and  $D(c | \neg g)$  are likely to be more or less uniquely conditioned; civil cases are different from crime cases, serious crime is different from less serious crime, and at case level the parties may be more or less equal concerning their material or political resources and concerning their need to have their legal rights protected.

Decision theory may thus assist arriving at a legal judgment being accurate concerning the evidence, accounting for the risk of loss of important values. Cullison (1969) aspires to be descriptive as well as normative and seems not to differentiate between the different needs of the various phases of a case-process: The basic decision of the trial phase represent any decision during a case's process. Then it is assumed that the legal indictment is naturally one among mutually exclusive and exhaustive alternatives. Cullison (1969) insists that the decision-theoretical approach is the only appropriate because it assists what he interprets to be the purpose of legal proof-standards: Its purpose is *primarily* to ensure sufficient relevant evidence for an accurate decision and is *not* to ensure peaceful conflict resolution through a collective of lay people's careful and commonsensical consideration of the evidence and arrival at the *truth* of the issues in a case. The latter interpretation is, Cullison (1969) claims, a misunderstanding:

There is much disagreement among authorities on whether a fact-finder applying the "preponderance of the evidence" standard is supposed to develop a distinct "belief" in the truth of the facts it finds or whether it needs only to decide what evidence preponderates. If, as some authorities indicate, a jury must be able to say "we believe  $f$  occurred" (rather than simply "our belief that  $f$  occurred is greater than our belief to the contrary") before they

can find  $f$ , then the threshold probability would be significantly greater than  $1/2$ . This view of course implies that the cost of [erroneously holding a defendant liable] is notably greater than the cost of [erroneously leaving the plaintiff with recourse]. Many authorities argue, on the other hand, that the threshold probability for ordinary civil cases should be  $1/2$ . (Cullison, 1969, p. 569)

In a footnote he fills in:

The most acceptable meaning to be given to the expression, proof beyond a preponderance, seems to be proof which leads the jury to find that the existence of the contested fact is more probable than its non-existence. Thus the preponderance of evidence becomes the triers's belief in the preponderance of probability. Some courts have boldly accepted this view.

Other courts have been shocked at the suggestion that a verdict, a truth-finding, should be based in nothing stronger than an estimate of probabilities. They require that the trier must have an "actual belief" in or be "convinced of" the truth of the fact by this "preponderance of evidence". (Cullison, 1969, p. 569 (footnote 44))

Cullison (1969) stresses that it is not wrong to instruct the jury that they must come to believe in whatever facts they find. But he believes that the "belief in the truth"-interpretation of the standards of proof will make people create a wide margin in the middle of the probability range where the decision goes to one party simply because the other carries the burden of proof:

If I am asked if I believe  $f$ , I understand that a "no" answer would leave open the question of whether I therefore believe  $\neg f$ ; I understand (especially if I ponder the matter) that there is a vast middle ground where doubts might keep me from really *believing* the truth of either  $f$  or  $\neg f$ . By contrast, if I am asked whether my belief in  $f$  is greater than my belief in  $\neg f$ , I understand that to say "no" is almost surely to imply that I believe  $\neg f$  more than  $f$ ; here, the only way to hedge is to claim that my degree of belief is precisely the same for both propositions. (Cullison, 1969, p. 571)

Cullison (1969) insists that the idea of "belief" being a necessary and sufficient test for "truth" is a symptom of a whole syndrome — a set of misperceptions caused by holding the primacy of the value of the legal process as being peaceful resolution of conflict, in which the "truth" is a necessary but subordinate aim.

This can also explain the resistance to using probability-concepts as an overt part of the legal process, because probability not only explicates certainty but uncertainty as well: Say that a poor farmer sued the government

for recovery after he lost his mule in its frightened escape from roaring jet-planes flying too low. A court would not admit recover by the evidence that 80 % of the jets in the air that day was Air Force (and not civilian), but the same court would admit recovery by the evidence that the farmer testifies to seeing the pilot wearing Air Force gear. The former kind of evidence is neither better nor worse than the testimony-evidence with respect to accuracy, but is worse with respect to peaceful conflict-resolution since it does not account for the asymmetry of the resources between the poor farmer and the government: It would be worse to erroneously deny recovery to this poor farmer than to erroneously judge a resourceful government liable — so the testimony is given more weight than the frequency-evidence because the overall aim dictates so.

Those holding the "belief is truth"- interpretation and resisting overt explication of doubt is therefore provoked by suggesting probability analysis and decision theory as a tool for the adjudication process. But, Cullison (1969) argues, the overall aim of peaceful conflict resolution does not itself dictate any specific interpretation of the standards of proof.

Cullison (1969) is good for explicating the arguments against the necessity of the "belief in the truth"-interpretation of the standards of proof. But he is less precise on the foundational arguments which should convince us why the "preponderance of probability"-interpretation serves the aims of the court. Sure, he appeals to the standard reasons:

[...] the very process of deciding what really happened in a case is at heart a matter of probabilities; [...] the great bulk of our trial procedures are ultimately justified by their long run effects [...]; [...] law courts are increasingly confronted with scientific evidence which they are ill-equipped to evaluate and utilize efficiently; [...] a comprehensive probabilistic analysis of fact-finding [can] give us better clues as to what factors influence fact-finding decisions, [and] to help us evaluate specific kinds of evidence, [and] to help us evaluate our rules of evidence and procedures. (Cullison, 1969:538-539).

Cullison (1969) unfortunately finds no space for justification: "[T]o outline [the probabilistic model] is a large enough project that, even without including an inquiry into the justifications and practical potentials, a great deal of basic ground must be left untouched." (Cullison, 1969:539). Then we are left wondering why one in a legal adjudication should prefer the question "Is your belief that  $f$  occurred greater than your belief that  $\neg f$  occurred?" (a closed space of possibilities) over the question "Do you believe that  $f$  oc-

curred?” (an open space of possibilities). The other scholars attempting the same kind of approach as Cullison (1969) (Kaplan 1965, 1968 and Finkelstein and Fairly 1970) are equally thorough when it comes to demonstrating their approach, but do not at all touch upon foundational issues.

## 4.2 Tribe (1971) The case against formal approaches

A host of legal scholars viewed and still view formal approaches to evidence and proof in the legal context with apprehension. I will let Tribe (1971) represent these by reviewing the arguments in his seminal *Trial by Mathematics: Precision and Ritual in the Legal Process*. For Tribe it is the axiomatic basis of formal approaches and the need for precision —or the *reduction* required for such precision — which is worrisome. Precision is at best difficult to attain in the legal context:

[...] although the mathematical [...] devices which a society embraces to rationalize its systems for adjudication may be quite comprehensible to a student of that society’s customs and culture, those devices may nonetheless operate to distort — and, in some instances, destroy — important values which that society means to express or to pursue through the conduct of legal trials. (Tribe 1971; 84; 6: p.1330)

It is important to note what Tribe states are *not* problems — because this, I believe, is what makes his paper more enlightening than other critiques of formal approaches:

- The problem is not the mathematical subject per se;
- legal cases frequently have issues in which probabilistic inference is directly involved;
- all factual evidence, including legal proof, is ultimately ”probabilistic”, in the epistemological sense that conclusions from observations are inductive;
- mathematical methods in the trial process are fine as long as it is appropriately conducted — mathematics is not more esoteric than other expert-knowledge;
- probabilistic inference is essentially about generalization;
- probability may represent a measure of a person’s confidence in the truth of a proposition about an event: Tribe knew Savage (1954) and saw the latter’s problem-situation as similar to trial-problems;
- mathematically derived assessment may supplement conventional evidence.

Tribe (1971) also acknowledges the worry about accuracy in a legal process, and understands the motive for wanting to develop various formal instruments to amend the legal actors' ability to deal with uncertainty. But he takes equally serious the dangers by uncritically endorsing formal approaches, recalling the abuse of calculus in the Dreyfus affair in France and in the American Collins-case in 1968:

[...] I suspect the lure of objectivity and precision may be increasingly hard to resist by for lawyers concerned with the reliability or simply successful, adjudication; partly because a critique of mathematical efforts to enhance the reliability and impartiality of legal trials may yield helpful insights into what such trials are and ought to be; and partly because such a critique may ultimately contribute to an appreciation of how rigour and quantification, once their real costs and limits are better understood, might actually prove useful in processes of decision-making. Most fundamentally, though, I write in reaction to a growing and bewildering literature of praise for mathematical precision in the trial process, a literature that has tended to catalog or to assume the virtues of mathematical approaches quite as uncritically as earlier writers tended to deny their relevance.

But Tribe (1971) is mainly concerned for the effect on the aims and values pursued by the legal system:

The difficulty [lies] in the discovery of an acceptable integration of mathematics into the trial process. (Tribe 1971: 1350)

I will below explicate Tribe (1971)'s worries. Note that the paper is a reaction to Finkelstein and Fairly (1970), Cullison (1969), and Kaplan (1968). All use the Bayesian rule for inverse probability and is why Tribe sometimes refers to the formal approach as the "Bayesian approach" or those using it as "Bayesians". Tribe's arguments concern three levels: The case-level; at the trial-institutional level; and at the procedural level.

#### **4.2.1 The case level: Formal approaches may cause loss of accuracy**

Tribe's arguments at this level proceeds via the hypothetical case of Finkelstein and Fairly (1971):

A woman is found in a ditch in an urban area. There is evidence that the deceased had quarrelled with her boyfriend the night before and that this boyfriend had been violent to her on several occasions. A knife, known to be the murder weapon, contains a partial palm-print the characteristics

of which are indistinguishable from the boyfriend's partial palm-print. But, because the print is partial, the expert can only say that 1 in 1000 of the general population would have such characteristics. This means that in a general population of 100 000 persons 100 of these would have such a print. In turn this would mean that the boyfriend is among these and that there are 99 other possible suspects — the palm-print is thus far from uniquely determining the individual who made the print on the knife. Tribe lets  $X$  represent the proposition that "The boyfriend, now the defendant, used the knife to kill his girlfriend",  $\neg X$  its negation, and  $E$  the proposition that "A palm-print resembling the defendant's was found on the knife that killed her".

### **(1a.) The meaning of "random probability"**

Having two print-samples assessed to be similar is relevant, but the significance of it is unclear: The presentation of its random relative frequency may be more misleading than enlightening; if given this figure at all, how should one delimit and justify the choice of suspect population? How should one account for the fact that other individuals than the defendant could equally well be the source, yet risking the fact-finders seeing the figure to signify the innocence of the defendant? (Tribe 1971:1355)

### **(1b.) Heuristics and moral responsibility**

The Bayesian approach needs an initial or prior probability of  $X$ . How easy is it for a lay fact-finder to simply ascribe a specific number which should both authentically and correctly represent his real prior assessment? And is  $P(X)$  better set at 0.33 or 0.43? It is the gravity of the situation, not the technicalities which is the problem: Would not most lay people being assigned the very serious jury duty hesitate just picking any figure as in a parlour game? Even if told that the choice of the prior does not matter much because it is the coherency which is wanted, would not a lay fact-finder worry that *his* choice will affect the outcome? And what if a person chose the prior to be 0.5? Does that signify equal weight to each *alternative* hypothesis due to inability to prefer among them or does it signify the weight to *one of the* hypotheses irrespective of the alternative? A Bayesian says we *should* consider relatively, but can we assume that people actually do it? This is far from obvious. The proponents of formal approaches like the Bayesian

seems to assume (a) that lay people, like the proponents, perceive formal modelling as instrumental, like a hammer or a knitting machine — having no consequence on the value-system of the situation in which it is applied and (b) that lay people actually do choose according to the set of norms for comparison which the proponents of a formal approach believes should be used. But lay people may not as easy as the proponents separate between the real world and the model, and even if we accept that we should separate, it does not mean that we practice it. Would not that produce rather nonsensical outcomes? These two complications must be accounted for when assessing the costs and benefits of formal approaches in practical decision situations. (Tribe 1971:1356)

**(1c.) The event as a member of a class: Initial categorization or prior probability?**

In most cases a statistic is usually presented for the purpose of classifying the present case: "70 % of all the injuries caused in this way is due to negligence, so this is claimed to be true in this case as well". Such a statement can shed light both on the kind of case had and on the choice of a prior probability. But how useful is it for the latter purpose in particular cases? The initial figure might overwhelm the jury — disabling them from seeing the complexities occurring in the wide space between that general statement and the case at hand. This is a problem for the partial palm-print too: A general statement about the random probability of the partial print may overwhelm the jury — disabling them from accounting appropriately for the individual case's softer kind of evidence. In addition the palm-print is detected (sampled) under quite other conditions than the event of the general statement. This is a general problem to the trial situation. A possible solution would be to instruct the jury about the necessity to differentiate between the general statement and the particular case, but Tribe worries that assuming a lay jury's ability to differentiate appropriately just introduces new uncertainties. (Tribe 1971: 1361)

**(1d.) The inputs and outputs of the Bayesian computer:**

How will the expert communicate the assumptions required for most modelling and can we trust that the modeller has constructed the best model for the case in question? Can we rely on the jury to detect possible flaws?

The number of conditioned variables in any given case will be large, there will be both objective frequencies and subjective probabilities, all processed through the Bayesian computer to yield a posterior probability: How may we expect the lay person to interpret this while performing the serious obligation of a jury service? Tribe cannot but be worried that this approach, intended to enhance uncertainty, instead introduces new sources of error. (Tribe 1971:1361)

#### **(1e.) The risk of bias towards easily quantifiable events**

A formal approach lends itself easily to quantifiable matters and to events whose nature is easily agreed. But can it deal with matters involving the mental state of the suspect? An expert-probability using forensic information is one thing, but a legal claim will require information about mental states as well. The Bayesians' regularly denotes the ultimate proposition by  $G$  for guilt. Even if their "guilt" is not legal, we may not assume that the jury accounts for this ambiguity. The inherent tendency in formal approaches to attend more to matters easily quantified and/or agreed may induce a shift of focus not benefiting the aim of the trial. (Tribe 1971: 1361-1366).

#### **(1f.) The risk of double and creative accounting**

Tribe worries that the Bayesian approach lends itself to double or wrongful accounting. *Double* accounting may occur if assessing the prior hypothesis in light of suspected evidence and then use that evidence to find the posterior probability: Being categorized as a suspect in the investigative phase is already a selection on the basis of evidence; would not being further assessed for the category of guilt on the same evidence constitute double accounting? The accurate application of Bayes' Theorem necessarily assumes that the evidence is independent of the prior suspicion, but in most trials these two will be hopelessly enmeshed. *Wrongful* accounting may occur due to the symmetry of the formal approach: the order in which the evidence is presented does not matter to the posterior probability. But interdependency between evidence might be hidden, intentionally or unintentionally, behind this property: A robbery is suspected to have been committed in the 30 minutes period between 3.00am and 3.30am. The robbery is known to have lasted exactly 15 minutes. A witness says he saw the suspect sitting in a car half a mile (800m) from the crime scene at 3.10am (evidence  $E_1$ ). Another witness says

that he saw the suspect sitting in a car half a mile (800m) from the crime scene at 3.20 (evidence  $E_2$ ). If both  $E_1$  and  $E_2$  are true then the suspect cannot possibly be the robber. But if  $E_1$  is treated first then one might be misled to think that  $E_2$ , when considered subsequently, corroborates with  $E_1$  to increase the probability of the hypothesis instead of invalidating it. Can we expect the jury to detect this? (Tribe 1971: 1366-1368)

#### **4.2.2 The trial level: Formal approaches may cause loss of social values**

Tribe (1971) is also concerned whether formal methods, if used in given trials, may be too costly with respect to the societal values pursued in actual legal trials. He has three arguments here:

##### **2a. Conflicting systems of values:**

The first argument concerns the values expressed by the presumption of innocence. The presumption of innocence is not just a rule of evidence, but a *normative principle* committing the adjudicators morally to the proposition that an accused is no less than his accuser or any other member of society entitled to freedom and respect. The intention is to (i) protect the accused from onerous restraints which are not needed to effectuate the interest in completing the trial; (ii) encourage an independent assessment of the guilt of the accused; (iii) preserve an atmosphere in which an acquittal in trial may be taken seriously by the community; (iv) sustain the attitude of refusing to acknowledge prosecutorial omniscience as long as the accused insists his innocence; and (v) sustain the obligation to listen to the accused before judging about his guilt. These values rest on the fragile ability of the fact-finder to suspend (i) the suspicion that most suspects are guilty and (ii) the fact that the suspect would not have been accused at all if there was not already a certain level of probability that he is guilty. Would not the ability to suppress these suspicions be weakened if repeatedly having to explicate prior probability of guilt? Here is thus an obvious conflict between the values of rationality, coherency, and transparency versus the values of protection of an individual's basic rights to freedom and integrity. (Tribe 1971: 1368-1372)

## **2b. The standard of proof: Towards overall predictability or towards situational moral commitment?**

What is the purpose of standards of proof? Is it a measure of the degree of error tolerable by the institution? Or is it the case-by-case swearing or ritual reminding of the fact-finders commitment to the obligation to strive to be as certain as humanly possible under the circumstances while attending primarily to the rights of the accused? Tribe holds that it is both: The system needs the first, the accused needs the second. Tribe worries that a systemic use of the Bayesian approach will tend to stress the first over the second.

## **2c. The need to mediate between abstract law and lay justice:**

The third argument concerns the legal institution's need to have modes of ascertaining truths and modes of conflict resolution which are grounded in its subjects' basic beliefs and norms. The institution needs its subjects to respect and abide by its decisions. This depends on the degree to which the subjects trust that its fact-finding apparatus is basically comprehensible. This is why lay fact-finders are involved at all: They are to mediate between the law in the abstract and the public's basic sense of justice. The law in the abstract is complex and alienating and an introduction of formal modes of proof would not make it less so. A typical lawsuit is not simply the objective search for truth, it is also a *ritual*: A complex pattern of gestures comprising "the society's last line of defence in the indispensable effort to secure peaceful settlement of social conflicts". Tribe worries thus that formal modes of proof might induce loss to the legal institution's fundamental need for legitimacy. (Tribe 1971: 1375-1377)

### **4.2.3 The procedural level: Formal approaches may cause loss to values sought via the procedural rules and norms of the legal institution**

This third level set of arguments concerns the use of formal approaches when formulating the rules of legal procedure: What are the consequences of incorporating formal thinking into the normative basis of legal adjudication?

**3a. Can decision models effectively represent the particular mix of values in given cases?**

Cullison (1969) noted the gravity of the injury and the resource-distribution among the parties as central variables affecting the choice of a threshold probability for guilt or liability. But are other dimensions thereby ignored? What about the losses caused by mistaken identity, mistaken intention, miscalculated statute of limitations? The particular mix of correct and incorrect decisions in a given case must of course condition the actual threshold of probability, but can the decision-theoretical model incorporate the values attached to the consequences in kinds of cases, of which any particular case is but an example? Tribe worries that the equations in given cases will be too complex. (Tribe 1971:1381)

**3b. Will emotional needs affect a person's probability-assessment?**

The decision-theoretic approach ignores the possibility that the legal context may, more than other contexts, be affected by the general phenomenon of preference-dependent probability-structures. There is the possible need for dissonance-reduction: Wishing that the accused is also the guilty may affect the assessment of the probability of the evidence, thereby affecting the standard of proof selected. Are such and similar needs more prominent in a legal trial situation? How? (Tribe 1971:1383-1384)

**3c. The standard of proof: Kind-based or case-based?**

Cullison (1969) suggests that decision-theoretical models can be guides to fact-finders in given cases. But, Tribe worries: The above problems are problems under any approach to the standard of proof. Could it be that fact-finders in given cases should rather abstain from expressing personal probabilities and preferences? That an appropriate selection of the standard depends on being separate from particular cases? (Tribe 1971: 1384)

#### **4.2.4 Concluding remarks on Tribe (1971)**

Tribe's worries are still valid expressions of a position on a still existing central and foundational dimension of conflict within jurisprudence with respect to assessments of evidence for practical legal purposes. I believe that this conflict is essentially irresolvable.

This implies that I also believe that formal approaches *cannot* be the one unifying methodology for legal assessment of evidence. Some of Tribes worries may now be less justified, but I cannot but agree that formal approaches are not on their own able to serve the symbolic or ritualistic purposes of the legal trial. This, I believe, has neither never been the intention of those advocating formal approaches to legal assessment of evidence. Just as Tribe fears the effect of formal approaches' commitment to rationality, accuracy, impartiality, and transparency, the increased attention to more formal approaches may have been provoked by the institution being already too biased to values serving the legal ritual aspects. A majority of legal scholars are neither pure protectionists nor probabilists. These would likely agree that one cannot achieve peaceful conflict-resolution through the symbolic/ritualistic aspect of negotiating legal rights and obligations in the latter stages of a trial if not having already secured a basis of justified knowledge about the facts in issue. The question is thus not whether or not the legal institution can integrate methodologies that protect the values of accuracy and impartiality but how it can be done without harming the basic aims/values of peaceful conflict-resolution.

### **4.3 A modern discourse on evidence and proof**

During the 1980's and 1990's the evidence-discourse in jurisprudence gained momentum. Three trends are visible: (1) The development of a diversified set of perspectives and models, normative and positive, of the legal adjudication of a case; (2) the development of the view that the legal processing of a given case poses a differentiated set of problem-situations with their own specific purposes — that different methodologies could and should be sought for these conditional purposes; (3) and the increased attention to *forensic science* and their methodologies for assessing forensic and scientific kinds of information.

One important development during the 1980's and the 1990's is the emergence of a host of alternative approaches to both descriptive and normative theories of evidence-assessment in legal situations: Cullison (1969)'s approach may be sorted into what became known as the Pascal/Bayes School of Probability and Uncertainty. But there are also the Bacon/Mill/Cohen School of Inductive Probability; the Shafer/Dempster School of Non-additive

Beliefs; and the Zadeh School of Fuzzy Probability and Inference — all being more or less formal approaches. Then there is the more informal and "fact-sceptic" or a-rational and social-norms-based approaches within *Legal Realism* — inspired by the works of Jerome Frank (1889-1957), Karl Llewellyn (1893-1962), and by sociological and anthropological theories on dispute-resolution. Finally one will find literature-inspired approaches dwelling on legal reasoning as narratives and rhetoric. Each of these approaches provides valuable insights to legal reasoning. Unfortunately there will be no space for studying these in this dissertation.

A second trend is the acceptance that the legal processing of a case is multi-staged: Each stage having its own set of problems and aims, each necessary but neither alone sufficient for ultimate multipurpose decision about the degree of legal responsibility. This means that it is not very fruitful to let the ultimate decision-situation at the end of the trial-phase represent all kinds of problems at any stage of the process. Schum (1986) proposed to see the processing of a case as a stage play, with a complex and changing plot evolving over three main acts having separate scenes in which different actors "play" different inferential roles:

**Act I. Discovery** Starts with the occurrence of a relevant event — a bribery, a murder, etc: Scene 1 involves the investigators, followed by the advocates, who attend to the discovery of possible hypotheses and information in a creative and informal manner; Scene 2 involves the same actors, but these attend now to the *elimination* of hypotheses in light of an increasing amount of information; and Scene 3 involves the same actors, but now attending to the *argument construction* for the means of evidence.

**Act II. Proof** Consists of the courtroom scenes involving the advocates and the fact-finders. Advocates attend to convincing the fact-finders of the strength of their arguments, exploiting both analytical and rhetoric skills.

**Act III. Deliberation and Choice** : Consists of the fact-finders only who attends to weighing of the evidence and the aims and finally decides on the overall weight of the evidence .

Peter Tillers suggested a slightly different model in his *Mapping Inferential Domains* (1986), but stressed the same: A case goes through several procedural phases having different needs and values, thus requiring different inferential "logics". And Cohen (1980), though concerned with medical diagnosis (arguably analogous to legal adjudication), suggested that *Bayesianism*

and *Baconianism* are not competitive normative systems, but complement each other as each seeks to optimize different sets of values at different phases of the processing of a case.

These scholars are signs of moving away from the meta-theoretical foundational debate and onto the practical work of developing, not one overarching methodology, but a 'toolbox' of different methodologies suited for different decision-purposes.

The third trend is the increased attention to the analytical norms and procedures of the forensic sciences. In 2005 Saks and Koehler published a paper in *Science* voicing suspicions that most of the sub-disciplines with the forensic sciences adhered to epistemological and methodological norms which were not suited to the aims and values of the legal institutions. Saks and Koehler referred to data provided by the Innocence Project, Cardozo Law School (New York): In 86 cases where DNA-profiling contributed to conclusion of wrongful conviction, 63 % involved forensic scientific testing-error and 27 % involved false or misleading testimony by forensic scientist. They claimed the error-rates were due to the analytical norms practiced by the traditional forensic sciences — norms which could develop due to the majority of the forensic scientists having either none at all or too little training under regular scientific norms. (Saks and Koehler 2005:892). Despite U.S. Supreme Court rulings in 1993 and 1999 that expert testimony had to answer to the Daubert-standard, studies of error-rates of many of the traditional forensic sciences in the U.S. continued to be poorer than that of diagnostic instruments and expert-conclusions used for medical diagnostic purposes (Faigman et al. 2002, Koehler 1996, Collaborative Testing Services Inc. 1993-2004).

Saks and Koehler (2005) attend to American forensic sciences, but the European forensic sciences have been equally isolated from the scientific culture. It should not come as a surprise if the error-rates of the European forensic services should be demonstrated to be similarly poor as well. In chapter five and six of this dissertation I present information indicating that the error-rates of the discipline of forensic bitemark-analysis are as poor as Saks and Koehler suggest and I document my claim that the analytical norms of this discipline are a main part of the explanation why it has not progressed beyond the level it has.

## 4.4 Conclusion

In this first part of the dissertation I have studied the more central analytical and institutional conditions, aims, and values of the criminal case process. The main analytical condition is that the questions typically concern (a) highly conditioned, natural, and unrepeatable events and (b) positive aspects as well as normative aspects. The main institutional condition is that the aims and values are complex and highly important to the parties involved in given cases, the public in general, and the legal institution: At the end of the first decade of the 21' century there is no disagreement that the ultimate aim of the criminal case process is to secure the parties' and the public's *confidence* and *trust* that the final court-decision is the best in terms of both truth and good. But a latent disagreement exists about the best *means* to achieve that ultimate aim — some insist on certainty in terms of accuracy, precision, objectivity and impartiality, while others insist on legal, social, and situational right in terms of negotiation, consensus-building, and conflict-reduction. This disagreement will still emerge in the aftermath of difficult cases and the arguments have not changed much since the 1960-1970's. This will be seen in the next part of this dissertation, when I analyze the Norwegian Torgersen-case.

The disagreement about the best means to secure confidence and trust is partly a constructed one — resting on the presumption that the problems of the latter part of the trial phase of the criminal case process can represent all the problems of all the phases of that process.

In the following parts of this dissertation I break that presumption, presuming instead that the criminal case process is a sequential decision problem according to Premise 2 and Premise 3 from the introductory chapter: In this perspective the problems of the criminal case process are differentiated over time and by substance and purpose — the problems chosen and decided on in one interval of time will condition the condition the choices available for analysis and decision in the next interval of time. This perspective allows for a differentiated approach to the means of problem-solving as well: The question is no longer whether or not one may use formal statistical procedures when assessing evidence or inference in the criminal case process, but which formal logical procedures are the best for assessing given kinds of evidence for given kinds of purposes in given phases of the criminal case process.

Under this alternative perspective, I will attend only to decision-problems typical at the end of the crime investigative phase and concentrate on means

of evidence based on imprint-traces and involving expert-analysis, exemplified by bitemarks on human skin without transferred components. The question will be:

which is the best methodological procedure for assessing the basic, *causal-logical*, evidential value or relevance of bitemark-means of evidence with respect to (a) a given formal legal indictment and (b) a standard of evidence being minimally that of Premise 1a in this dissertation —

**Premise 1a. A basic standard of evidence-basis for crime investigative decisions:** A decision about the basic causal mechanism of a crime event is *evidence-based* if all the reference-groups and -terms causally and logically necessary for the decision are explicit and unequivocal and (a) enable person independent assessment of the probabilities of the events involved and (b) enable person-independent assessment of the risk of deciding wrongly about the causal mechanism — thereby contributing to (i) the conviction of a true innocent person or the acquittal of a true responsible person; (ii) the reduction of resources available to other cases; (iii) the public losing trust and confidence in the crime investigative services and the legal institution ?

To answer this question I must first examine the procedures which are used, historically and currently, by crime investigators and experts for solving this problem. This is the topic of the next and second part of this dissertation.

## Part II

# Determining the relevance of bitemark-means: Current epistemological norms and methodological procedures

In this part of this dissertation I proceed to study the current epistemological norms and methodological procedures for a subgroup of crime investigative decisions: Decisions about the basic causal-logical evidential value of means of evidence involving (a) imprints without transferred components and (b) expert-knowledge for diagnosing the imprints' causal object and time of occurrence. To illustrate I will use human bitemarks on human skin. The question in this part of the dissertation is:

**Question 2.** Are European crime investigative decisions about the evidential value of bitemark-means evidence-based to the standard of Premise 1a of this dissertation?

This main question will be assessed in light of the conclusions about two related questions.

**Question 2a.** Were the successive decisions about the evidential value of the bitemark-means in the Norwegian Torgersen-case evidence-based to the standard of Premise 1a. of this dissertation?

**Chapter 5** introduces the Norwegian Torgersen-case and discusses the relevance of the sources available with respect to answering question 2a. A brief introduction to the Norwegian legal system is provided in Appendix 1.

**Chapter 6** analyzes the first bitemark-expert's (in 1957/1958) justification for his diagnosis of the bitemark. An addendum to the chapter presents the defence counsel's argument that the case qualifies for review.

In **Chapter 7** I study the modern bitemark-experts' (in the period between 1997 and 2006, court-appointed as well as party-appointed) justification for their diagnoses. An addendum to the chapter presents the Norwegian Criminal Cases Review Commission's position on evidence-theoretical issues.

The second question under the main question is:

**Question 2b.** Are bitemark-experts' decisions about hypotheses investigated for more general knowledge-purposes (a) substantially relevant for practical forensic diagnoses and (b) evidence-based to the standard specified in Premise 1?

In **Chapter 8** I assess this question in light of studies published in scientific journals between January 1976 and December 2008.

# Chapter 5

## The decision-problem exemplified: The Norwegian Torgersen-case

In this chapter I will first introduce the Norwegian Torgersen-case and its court-history. In the last section I assess the relevance of the sources with respect to the question I want to assess — i.e. **Question 2a:** whether the successive decisions about the evidential value of the bitemark-means in the Norwegian Torgersen-case were evidence-based to the standard of Premise 1a. of this dissertation.

### 5.1 The Norwegian Torgersen case

1

At 1.27 am, early Saturday morning the 7. December 1957, the fire department in Oslo was alerted to a fire in the basement of a block of flats in Skippergata 6b, in the poorer harbour area of Oslo. It was the tenants on the ground floor apartment who had called. The fire brigade arrived at 1.30 am and discovered the body of a dead woman covered with smouldering scraps of wood and cardboard. The police was alerted and arrived immediately — the crime police and the medical examiner arrived later, at 2.30 am. The medical examiner's report (Eskeland, 2000: Vol. I:242-249) states that the woman

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<sup>1</sup>Four sets of documents are the main sources of this section: Eskeland (2000), Eskeland, (2005), Prosecution (2005), and Commission (2006)

was found half naked, with her clothes torn off. She had bled significantly from an injury to her head and from her mouth and ears. Only mild signs of rigor mortis were observed on the crime scene. The report concluded that the most likely cause of death was asphyxiation by manual strangulation and/or head-injury by blunt force. Time of death was not commented on in the report. The woman's face also had several areas of bruising, there were signs of rape or attempted rape, and on her left breast, around the nipple, was observed a patterned mark stated to look like a bite-mark. The crime scene investigation gave reasons to believe that the actual murder had occurred in the entrance-area towards the steps leading to the back yard of the building. A pool of blood and faeces was observed here as well as a piece of RJ's underpants and some coins.

The dead woman was identified as Rigmor Johnsen (RJ) — a 16 years old girl who lived with her family in the same building as the fire. The last reliable observation of RJ was at 11.00pm on the ground floor in that building, in the entrance area, by a neighbour — OE. RJ was observed being with a man not known by this neighbour.

RJ's movements until 11.00pm are not disputed: Earlier that evening RJ had been together with her boyfriend (SEJ). They had been out for Christmas-beer, and had parted as SEJ took the tram home at 22.30-22.40. She then walked towards her house a few hundred meters away and stopped to buy apples. The shopkeeper told the police that RJ had complained that a man was annoying her and that she (the shopkeeper) had told the man to leave RJ alone. Nevertheless, RJ and the man went away together. They were seen by several witnesses as they approached RJ's Skippergata 6b and, last, inside this building by the neighbour woman, OE.

OE had been on her way to clean a store across the street. She came back at 11.50pm together with her husband. He went straight up to their flat, while OE went out into the backyard to empty some garbage. She had noted a pool of "blood and sick" in the corner by the door out into the backyard. She had told her husband about it, commenting it to be yet another sign of the bad neighbourhood they lived in.

At 0.58 am, the same morning, 500m from the crime scene, a police-patrol stopped a man — Fredrik Fasting Torgersen — for not having lights on his bicycle. They also suspected the bike was stolen. Torgersen was uncooperative and they decided to take him in for further questioning. On their way to the police-station Torgersen tried to escape, but failed. At the police station the information about the incident in Skippergata 6b had arrived.

The newspapers that day, Saturday, wrote that a young man was suspected and arrested. The following Tuesday, 10. December, the newspapers showed a photo of Torgersen.

### **5.1.1 The crime investigation**

The gruesome nature of the murder caused an intense search for information to answer the natural questions: Why, how, who had murdered RJ, and was Torgersen involved? Forensic samples were identified, collected, and analyzed, and complemented by information from witnesses to events directly connected in time and place to the murder and to Torgersen, who soon came to figure as the main suspect. A couple of other suspects were considered too, but it is difficult to establish from Eskeland (2000) how the investigators imagined the suspect population, how they arrived at those who did briefly figure as potential suspects, how important any of these were at any stage of the investigation, or how much information was gathered for the elimination of each of these. Torgersen was known by the police from other incidents: He had a previous sentence for violence against the police, and at the time of the arrest he was on parole from prison due to a conviction for rape. Finally, Torgersen was perceived to have had the opportunity as he was in the area in the time period of the murder. In early spring 1958, Torgersen had become the single suspect.

#### **d. The investigator's theory**

In May/June 1958 the investigators recommended the following theory to the prosecution: Torgersen was the person who was together with RJ between RJ's stop at the fruit-stall and 11.00pm in the entrance area of her block. Some time between 11.00 and 11.30, in the entrance area towards the door out to the backyard Torgersen tried to rape RJ and then hit and strangled her. He then carried her out into the backyard, opened the trapdoors, went down and lay the body on the immediate inside. He then went up to collect the coat, hat, scarf, and bag of apples which he placed on the inside of the body. There was no light in the basement. He built the fire in the dark. He then discovered not having matches. Torgersen decided to go home for matches — he walked to a cab-station 700m away, was driven to his home (2,6km), arriving at ca. 12.00pm. He changed clothes while playing music and left again at ca. 00.30am, and arrived by bike at Skippergata 9. He

then walked across and in to nr. 6b, through to the backyard, opened the trap-doors, and used 11 matches to light the material covering RJ. He walked out the same route, fetches his bike at Skippergata 9 and cycled homeward. After ca. 450 m., at 00.58am, he was stopped by the police.

#### **e. Torgersen's explanation and the defence counsel's theory**

Torgersen's defence counsel had access to the same information as the investigation and must be presumed to have gathered additional information as well. Torgersen and his defence counsel argued the following explanation: Friday 6. December, at ca. 11.00pm, outside a cinema in Oslo Torgersen met a woman called Gerd (not identified at the time of the first trial) whom he knew superficially. They went home to his house, where Torgersen lived with his mother and two brothers. They arrived here at ca. 11.30pm. They stayed in his room for an hour, playing music. He changed clothes. At 00.30am he takes Gerd home by a bike borrowed from his young nephew. They separated at Akersgaten and Torgersen walked and cycled alone the 750m to the place he met the police patrol at 00.58am.

## **5.2 The court-history of the Torgersen-case**

### **5.2.1 The public prosecutor's indictment**

The case against Torgersen was accepted by The Director of The public prosecutions the 12. May 1958. The indictments delivered to Eidsivating Court of Appeal were as follows:

#### **I. The [Norwegian] General Penal Code Section 192 [Chapter 19. Sexual offences]**

##### **Section 192.** Any person who

- a) engages in sexual activity by means of violence or threats, or
- b) engages in sexual activity with any person who is unconscious or incapable for any other reason of resisting the act, or
- c) by means of violence or threats compels any person to engage in sexual activity with another person, or to carry out similar acts with himself or herself

shall be guilty of rape and liable to imprisonment for a term not exceeding 10 years. In deciding whether the offender made use of violence or threats or whether the aggrieved person was incapable of resisting the act, importance shall be attached to the whether the aggrieved person was under 14 years of age.

A penalty of imprisonment for not less than two years shall be imposed if

- a) the said activity was sexual intercourse, or
- b) the offender has rendered a person in such a state as is specified in the first paragraph (b) in order to engage in sexual activity.

Imprisonment for a term not exceeding 21 years may be imposed if

- a) the rape has been committed by two or more persons jointly
- b) the rape has been committed in a particularly painful or offensive manner,
- c) the offender has previously been convicted and sentenced pursuant to this provision or section 195, or
- d) as a result of the act the aggrieved person dies or sustains considerable injury to body or health. Sexually transmitted diseases and generally infectious diseases, cf. section 1-3, No. 3, cf. No.1, of the Act relating to control of communicable diseases, shall always be deemed to be serious injury to body or health pursuant to this section.

Any person who through gross negligence is guilty of rape pursuant to the first paragraph is liable to imprisonment for a term not exceeding five years. If such circumstances as are specified in the third paragraph subsist, the penalty shall be imprisonment for a term not exceeding eight years.

parts 1 and 3, relate to part 2, all relate to part 4, for having committed an act which intention was to initiate a not completed crime, namely by violence or by installing fear for life or health having forced someone to commit indecent intercourse, as the indicted has a previous conviction by the same statute, by having, Friday 6. December 1957 between 11.00pm and 11.30pm, in the entrance-area of Skippergata 6b, Oslo, tried to force about intercourse with 16 years old RJ by strangulating her and/or hit her head violently on the edge of the lower step of the stairs and tear apart her underwear.

## **II. The General Penal Code Section 233 [Chapter 22. Felonies against another person's life, body and health],**

**Section 233.** Any person who causes another person's death, or who aids and abets thereto, is guilty of homicide and shall be liable to imprisonment for a term not less than 6 years.

If the offender has acted with premeditation or has committed the homicide in order to facilitate or conceal another felony or to evade the penalty for such felony, imprisonment for a term not exceeding 21 years may be imposed. The same applies in cases of repeated offenses and also when there are especially aggravating circumstances.

parts 1 and 2, for having caused another one's death as the murder is committed in order to diminish or hide another crime or to evade punishment for such a crime, and or under particularly aggravating circumstances, by having, at the same time and place as under I, caused the 16 years old RJ's death by strangulating her with hands and/or hit her head violently against the edge of the step of the lower stairs as he committed the murder for diminishing, hide, or evade the punishment for the indictment I.

## **III The General Penal Code Section 148 [Chapter 14. Felonies against public safety],**

**Section 148.** Any person who causes any fire, collapse, explosion, flood, maritime damage, railway accident or aircraft accident which may easily result in loss of human life or extensive destruction of another person's property, or who abets thereto, shall be liable to imprisonment for a term of not less than two years and not exceeding 21 years, but not less than five years if as a result of the felony any person dies or is seriously injured in body or health. An attempt may be subject to the same penalty as a completed felony.

for having caused fire by which loss of life easily could have been caused, by having, the night before Saturday 7. December 1957, caused fire in the basement of Skippergata 6b, Oslo, by collecting a heap of rubbish, paper bags, cardboard, a dry Christmas tree and old wood material and lighting with matches whereby loss of human life easily could have been caused, if the fire had not been detected in time. (The Norwegian General Penal Code 1902/2005, Review Commission 2006:14-15)

### 5.2.2 The trial and the court's decision in June 1958

The trial was by jury directly.<sup>2</sup> During its two weeks in June 1958 the jury heard 71 witnesses and 19 experts in relation to several types of physical traces. The jury decided the prosecution's evidence was convincing to the instructed degree of probability. On the 16 June 1958 Eidsivating Court of Appeal delivered judgement, accepting that all the facts in issue in all the allegations of the prosecution against Torgersen had been proven to the required standard:

[Torgersen] is convicted for crimes against the General Civil Penal Code Section 192, first and third part, relate to second part, related to Section 49 [Attempt], and relate to fourth part, related to Section 61 [Suspended sentence and grounds for reducing or increasing the penalty] Section 233, first and second part, and Section 148, first part, all related to Section 62, and is sentenced to imprisonment for life.

In case of release he is to be submitted to rules of preventive detention/supervision in accordance with General penal Code 39 nr.1 a-f as long as seen necessary, although not beyond 10 - ten - years without the court's approval. (Review Commission 2006:15)

Torgersen appealed to the Supreme Court, concerning procedural aspects, the sentencing, and the preventive supervision. This appeal was rejected by the Supreme Court's Appeal Committee in a ruling 1. November 1958. At the same time Torgersen addressed a motion for retrial of his case to Eidsivating Court of Appeal in November 1958, but withdrew it in July 1959.

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<sup>2</sup>See Appendix: Brief overview of the Norwegian legal system.

### **5.2.3 A miscarriage of justice?**

A second motion for retrial was addressed to Eidsivating Court of Appeal 22. March 1973. This was rejected 27. June 1975. It was appealed, but sustained by a High Court Ruling 31. May 1976. A third motion for retrial was addressed to Borgarting Court of Appeal in September 1997. The motion was rejected August 2000, appealed, but sustained by High Court Ruling of 28. November 2001.

In the aftermath of both these rounds in the Norwegian Courts caused heated public debates with rather hostile fronts emerging. Torgersen's defence counsel argued that he had been wrongfully convicted: The overall evidence, including the forensic evidence, had been biased against him and the three necessary means of evidence involving forensic items — the bitemark on RJ's breast, excrement from the main crime scene and from the suspect's clothing/shoe, and spruce-needles from main crime scene and from the suspect's clothing — had been based on analyzes which were unreliable, incomplete, and "unscientific".

But Torgersen and his counsel were not able to convince the judges of the Appeals Committee of the Supreme Court. It sustained the Court of Appeals decision to reject the motion by High Court Ruling of 28. November 2001.

### **5.2.4 The last effort: The Norwegian Criminal Cases Review Commission**

A last motion for retrial was decided in 2004, when the **The Norwegian Criminal Cases Review Commission** (Commission) was established as an independent legal body.

The Commission is not an ordinary legal body — it may not itself produce legally enforceable decisions in given cases, but, if reopening is decided, the commission will refer the case back for retrial at the same court-level it was last decided. Only if new circumstances, new evidence, or other conditions have come into existence since the last court decision may the Commission decide to reopen the case by sending it back to court for retrial. (*The Norwegian Criminal Procedure Act 1981/2006: Sections 390-393*).

In Eskeland (2005) (the document containing the motion to have the case reviewed by Commission) Torgersen's counsel argued that the Torgersen-case is a rare case of exception where the courts have delivered the wrong decisions in total five times. The counsel argued that both sections 391, 1 and 3 and

section 392 of The Criminal Procedure Act were fulfilled. The means of evidence relevant to this dissertation, the bitemark-means, figured in both arguments:

One forensic odontological expert witness intentionally lied when testifying about the bite-mark during the trial (Eskeland 2005:80)

The bitemark excludes that Torgersen can be the perpetrator. This is new. (Eskeland 2005:83)

All the experts to today, including the Norwegian Board of Forensic Medicine, with the exception of professor [odontology] Tore Solheim [footnote 70: "Solheim's view cannot be taken seriously. See section 9.2 above and chapter 8, section 7"] agree that the bitemark on Rigmor Johnsen's breast is not identical to Torgersen's teeth. All the experts today, including The [Norwegian] Board of Forensic Medicine, with the exception of professor Tore Solheim [footnote 71: "See previous note"], agree that there is no disciplinary basis on which to conclude that there is a probability that the bitemark connects Torgersen to the murder. This includes the British experts [MacDonald and Whittaker, the court-appointed experts, see chapter ], who openly acknowledges that they have no disciplinary basis for their conclusion "very likely". The same applies for the Supreme Court's Appeals Committee in 2001 (Supreme Court Decision 2001). In 1958 the bitemark was presented as identical to Torgersens teeth and the evidence was perceived as an almost certain evidence that Torgersen was guilty. (Eskeland 2005:76-79)

But the Commission was not convinced: On 8. December 2006 it concluded that the conditions required by the sections 391 and/or 392 in the Criminal Procedures Act were not met (Commission 2000). Nothing new was seen added to the motion which had not been considered several times by previous courts and latest by the Supreme Court in 2001 (The Commission's arguments concerning the bitemark-means and concerning legal evidence and proof is presented in an addendum to chapter 7).

The repeated assessments and decisions about the bitemark in this case will be seen to represent a series of individual decisions about the bitemark-means. In the next two chapters I will analyze the reasoning towards the repeated decisions that the bitemark-means was basically (causally/ logically) positively relevant to the indictment General Penal Code Section 192 and/or Section 233. The aim is to identify the epistemological norms and methodological procedures of that reasoning and to assess whether these norms and procedures are able to evidence-base these decisions to the standard of Premise 1 in this dissertation.

But before proceeding to this assessment I must assess whether the sources of information is sufficiently relevant.

### 5.3 The relevance of the sources

Are the sources available about the Torgersen-case relevant for identifying and assessing the epistemological norms and methodological procedures behind the investigative decisions about the case-specific value of the bitemark-means?

#### 5.3.1 *Excerpts to the High Court's Appeal's Committee, Criminal Case Nr. 2000/1148, Fredrik Fasting Torgersen v. The Public Prosecution 2000; Volumes I-IV.*

The first and main source is Stle Eskeland's *Utdrag til Hyesteretts Kjremlsutvalg Straffesak Nr. 2000/1148 Fredrik Fasting Torgersen mot Den Offentlige Ptalemyndighet 2000; Volumes I-IV (Excerpts to the High Court's Appeal's Committee, Criminal Case Nr. 2000/1148, Fredrik Fasting Torgersen v. The Public Prosecution 2000; Volumes I-IV)*. This source will be referred to as "Eskeland (2000)".

Eskeland (2000) contains the primary material: Copies or transcripts of initial and later police and crime scene personnel reports; fire brigade reports; initial and later witness- and suspect-interviews; correspondence between the parties (court, prosecution, and defence counsel); and the reports provided by the forensic or scientific experts requested to assist on the assessment of physical traces as well as the correspondence between these, their parties, and the Norwegian Board of Forensic Medicine.

I have no reason to question the reliability of Eskeland (2000) — neither the accuracy nor its authenticity. It is not perfect, but is within the limits of what can be expected of this kind of information given the purpose of Eskeland (2000) as well as the purpose of this dissertation.

The mere volume of the collection suggests that it contains "everything". But of course it does not. Eskeland (2000) is first of all the information collected given the needs of Eskeland who had taken on to defend Torgersen from the time he decided to motion for retrial for the second (or, strictly,

the third) time in 1993. The kind of information relevant for this purpose is clearly less than perfectly relevant for my question about the reasoning of the crime-investigators.

Eskeland (2000) is what it is due to the original purpose and due to the traditional role of the Norwegian defence counsel: The latter led to seeking information relevant for decreasing the certainty of the court's conclusion about the indictment. The former relevance issue is more serious for my purposes: Eskeland (2000) has very little information directly relevant to the *crime investigator's* reasoning. It includes information about the reasoning of the forensic experts. But only about this reasoning as it is presented in their written reports.

The main explanation is that only the court's adjudication of evidence during the trial phase can constitute reasons for retrial. Whether a wrongful adjudication is caused by incorrect weighing during the trial phase or during the investigative phase does not matter much: It is the court which has to ensure that the information used in the means of evidence in the case is the best possible for the legal purpose. The information about the crime investigator's reasoning was therefore less relevant for the purpose of the counsel.

A second explanation is that the original holder of all the potentially relevant information — the police and the prosecutor — either did not find it relevant or could not release it because it does not exist. To take the latter first, a person subject to a Norwegian police investigation has in principle a right to access the same information as the police investigator, but in practice this principle might come into conflict with other legal or investigative needs. A grey zone of judgement will necessarily exist here. However, it is unlikely that this factor has been important in this case as the case was old. More important, then, is the reason that the police simply could not release such information because it does not exist in the written format. I am not able to document whether Norwegian investigators in 1958 were obliged to log the investigation. Neither am I able to document whether investigators in 1958 could influence the mandate and the performance of medical and odontological experts.

The Prosecuting Authority in Norway was contacted for access to information about the investigation of the case. But the cost of gaining such access was decided too high, both in light of what I expected to find and in light of the purpose of the information. The access to governmental bodies' documents are in Norway in principle open to the public by law, but will

in practice be conditioned by legal issues of privacy. Documents relating to crime investigations are by nature sensitive to privacy issues and access is authorized by application to several public bodies — a procedure which is time and labour consuming. An authorization also involved the risk of being imposed publication clauses. And the risk was still that not even this additional information would be relevant for my purpose. All in all, I decided thus not to pursue access to this information.

The court-proceedings from 1958 are available but do not contain the detailed content of the examination of the experts and the investigator. The minutes only inform about who was examined when by whom.

A fourth possible reason why Eskeland (2000) does not contain information about the reasoning of the investigators concerning the bitemark-means is that the police investigators simply was not much involved in neither the communication/mandating of the expert-analyzes nor the construction of the means of evidence. It is possible that the mandate was formulated rather generally by the court when initially and formally appointing the expert as a court expert, and it is possible that specification beyond the mandate was done by the expert himself and/or in communication with the prosecutor of the case. The modern investigator may be more involved in the mandating of experts, but I am not able to document anything about this relationship, not in the Torgersen-case and not more generally.

### **5.3.2 Eskeland (2005): *The evidence in the Torgersen-case***

A second source of information is Stle Eskeland's *Bevisene i Torgersensaken* ("The evidence in the Torgersen case") from 2005. This source will be referred to as "Eskeland (2005)".

Eskeland (2005) contains the argument of the motion for retrial addressed to the Norwegian Criminal Case Review Commission in 2004. This document is not very relevant with respect to the reasoning of the investigator on the case, but it illuminates that the role of a legal defence counsel is different from the role of a scientist or an investigator. Concerning the bitemark-evidence Eskeland (2005) argues that

All the experts today, including the Board of Forensic Medicine, with the exception of professor Tore Solheim [footnote 71: "Solheim's view cannot be taken seriously by anyone. See section 9.2 above and chapter 8 section 7."] agree that the bitemark on Rigmor Johnsen's breast is not identical to

Torgersen's teeth.

All the experts today, including the Board of Forensic Medicine, with the exception of professor Tore Solheim [footnote 72: "See previous note".] agree that there is no scientific [forensic odontology] basis for concluding that it is probable that the bitemark connects Torgersen to the murder. This applies also to the British experts [the court-appointed experts in 1997-2006], who openly acknowledges that they do not have any scientific [forensic odontology] basis for their conclusion "very likely". Eskeland (2005:77-78)

On first reading of this and knowing that the case had been repeatedly rejected (and possibly requiring my gullibility) I did indeed worry that something was seriously wrong in the Norwegian legal institution. But having had the time to study all the material I see that the statement above can only be true if the term "identical" and "probable" are interpreted in the most formal sense. Such precision is not available in practical forensic diagnoses. The purpose of this kind of information is not primarily to enlighten the reader about the nuanced positions of the experts. The purpose is to influence the readers' basic sentiment towards the case — in order to ultimately protect the defendant's rights. As said, substantiating the argument in this way is perhaps appropriate for the counsel in trial phase modus, but is almost "dangerous" as a source of information about the reasoning of the successive investigators on this case. Eskeland (2005) is therefore used only for information about the sub-claims possible in this case.

### **5.3.3 The Public Prosecution (2005): Statement to Fredrik Fasting Torgersen's Motion of 25. February 2004 for retrial of criminal case adjudicated by Eidsivating Court of Appeals 16. June 1958.**

A third source of information is the report produced by the Norwegian Higher Prosecution Authority on request of the Norwegian Criminal Case Review Commission: Oslo Statsadvokatembeter (2005) *Ptalemyndighetens uttalelse til Fredrik Ludvig Fasting Torgersens begjring av 25. februar 2004 om Gjenopptakelse av straffesak pdmt av Eidsivating lagmannsrett 16. juni 1958* (The Public Prosecution (2005): Statement to Fredrik Fasting Torgersen's Motion of 25. February 2004 for retrial of criminal case adjudicated by Eidsivating Court of Appeals 16. June 1958). This source will be referred to as "Prosecution (2005)".

Prosecution (2005) corrects for some of the relevance-issue posed by Eskeland (2000), but has the same basic relevance issues as Eskeland (2005). The Public Prosecution (2005) may be expected to be less biased than Eskeland (2005) in one sense: Unlike the defence counsel, the prosecution is formally obliged to attend to all the aspects of all the necessary evidence of the case. However, other communication-techniques are available for one not wanting to divulge too much. Anyway, the arguments of Prosecution (2005) are related to the legal formal conditions for retrial, they are in the terms of the prosecutor-role, and contain thus less information about the investigators' reasoning.

#### **5.3.4 The Norwegian Criminal Case Review Commission (2006): *Decision in case nr. 2004-00071, Fredrik Ludvig Fasting Torgersen v. The Public Prosecution Authority***

A fourth source of information is the final report of the Norwegian Criminal Case Review Commission from 2006: *Beslutning i sak nr. 2004-00071, Fredrik Ludvig Fasting Torgersen mot Den offentlige ptalemyndighet* (The Norwegian Criminal Case Review Commission (2006): *Decision in case nr. 2004-00071, Fredrik Ludvig Fasting Torgersen v. The Public Prosecution Authority*). This Source will be referred to as "Commission (2006)".

Commission (2006) is more relevant to my question about the crime investigative reasoning and may be said to complement Eskeland (2000). Commission (2006) contains assessments of the arguments of the parties as well as assessments of the expert-reports generated over the years. It also contains a lengthy justification for the Commission's decision in the Torgersen-case.

But not even the information of Commission (2006) is optimal for my purpose in this dissertation — again because the Commissions' mandate was to assess the defendant's motion with respect to the requirements of the Criminal Procedure Act's Section 391 and 392. This mandate is not very different from my question in this dissertation. We are both investigating the evidence-basis of the necessary means of evidence in the Torgersen-case, but Commission (2006) seems to hold that the decision-problems of the trial-phase are representative for all decision-problems occurring in the different phases of the criminal case process — it does not differentiate the problems as I do by Premise 2 and Premise 3 from Chapter 1.

### 5.3.5 Are the sources sufficiently relevant?

In this dissertation I want to identify and assess the epistemological norms and methodological procedures adhered to by the *crime investigators*. But are the sources relevant for this question if they do not contain much information about how these investigators reasoned?

Eskeland (2000), Eskeland (2005), Public Prosecution (2005), or Review Commission (2006) cannot be said to be optimal sources of information: All have their own purposes which are more or less different from mine. And any more directly relevant information may not even exist.

But the sources do contain information which is *indirectly* relevant to my question: All the expert-reports requested for the investigative assessment of the bitemark-means are available. I believe I may use these to *represent* the reasoning of the crime investigators:

- (1) It is *known* that all the courts as well as the Review Commission (2006) decided that *all* the three indictments of the prosecution were proven to the required degree of provability by the prosecution's means of evidence; and
- (2) It may be *assumed* that the bitemark-means was a necessary *necessary* means of evidence for at least one of the indictments — that one or two of the indictments could not have been found proven to the standard required *without* the bitemark-means:
  - a. nobody voiced the argument that the bitemark-means is superfluous to the indictment(s),
  - b. the bitemark-means was repeatedly reinvestigated, and
  - c. the costs involved by these reinvestigations (in terms of money, time, and public confidence) were accepted.

If this is true we also know that the following consequences must have been found sufficiently proven as well:

- The skinmark observed on the victim's left breast is a human bitemark;
- Torgersen's biting-mechanism by April 1958 is the causal source-object of the bitemark;
- The bitemark occurred simultaneously with the lethal and rape injuries;

- There was only one human agent other than the victim present during the time-interval specified for the lethal injuries.

All these consequences or *bitemark-means* criteria must each be sufficiently relevant to the bitemark-means for the bitemark-means to be positively relevant for the indictment(s): If the latter was found so, then by logical implication, each of these consequences must have been found relevant to a degree which made the bitemark-means more probable than not.

The three first consequences or criteria rest directly on the conclusions of the bitemark-experts' analyzes of the bitemark and Torgersen and other's biting-mechanisms. We know that all the court-appointed bitemark-experts recommended holding Torgersen as the most likely biter. The experts' justification for these conclusions were presented in both *oral testimonies* during the trial and other court-hearings and *written reports*. As said above, Eskeland (2000) does not contain information on the oral testimonies, but contain all the relevant expert-reports. Eskeland (2005), Public Prosecution (2005), and Review Commission (2006) contains information about the oral testimonies during the court-hearings as well.

The consequences of accepting the bitemark-means as relevant and necessary for the indictment(s), I hold, is good enough reason for letting the experts' reasoning towards the three first criteria represent the crime investigators reasoning about them. The last criteria — that there was only one human agent other than the victim present during the time-interval specified for the crime-event — cannot be assessed by any one particular scientific or forensic expert-domain. It must be assessed by the crime investigator via case-particular information in the form of both lay and expert observations. I was not able to find such information in relation to the bitemark-means. The criterion of one or more offenders is necessary for other means of evidence as well but I could not find such information for these either. As said above, not having written information does not mean that the question was not assessed. To avoid letting the absence of information about the assessments of this criterion undermine my later analyzes I will impose the following assumption:

The criterion that there was only one offender in the Torgersen-case is fulfilled to the required degree of certainty. The Torgersen-case is thus an example of a one-offender case.

One possibility remains: Perhaps the crime investigators actually did find the experts reasoning unjustified but were overruled by the legal agents? This would imply that the crime investigators could maintain a standard of justification which was different than both the bitemark-experts and the prosecutor. This is of course possible but not very likely, particularly in light of Commission (2006): The standard held by the investigators more likely than not agreed with the standards of the prosecutor and the bitemark-experts in this case.

Under the assumption that there was only one offender in the Torgersen-case, I find it safe to let the justifications of the bitemark-experts represent the justifications of the crime-investigators with respect to the decisions about the bitemark-means.

### **5.3.6 Independent decisions about the bitemark-means?**

The repeated assessments and decisions about the bitemark-means in the Torgersen-case will be seen as a series of separate decisions about a particular *kind* of bitemarks under a particular *kind* of case-conditions — as a *sample* of decisions from the European population of such decisions. This is clearly not a sample in the statistical sense of that notion as the decisions are dependent on each other in too many respects, being independent only by having been made by different investigators and experts. *Ideally* I should have collected a much higher number of cases with the same kind of bitemarks occurring under same kind of crime events and being investigated for the same kind of purposes from *different* European jurisdictions. That would have been better with respect to the first question of this dissertation. But bitemarks are relatively few compared to other kinds of forensic traces. And, if a sufficient number of such cases do exist, the accessing and processing of case details required for establishing such an ideal information-basis would extend far beyond the limits of a PhD-dissertation. To amend for the biasing effects of dependence I will also study the epistemological norms and methodological procedures of bitemark-experts when these produce general knowledge of phenomena and mechanisms relevant for forensic diagnoses of bitemarks on human skin. This study is presented in chapter eight of this dissertation.

In the next chapter I will assess and decide about the evidence-basis of the first decision about the bitemark-means in the Torgersen case — in the

terms of the first written report provided by the first bitemark-expert in 1958.

## Addendum

### The counsel's arguments for retrial of the Torgersen-case

Torgersen's defence counsel could not but see that the court's assessments of means of evidence as basically flawed and that this was evident to anyone not directly involved on the sides of the police-investigation, prosecution, or the judges of the court. Eskeland (2005) argued therefore that the Torgersen-case was an example that certain social-psychological mechanisms had been at work within the legal community: The authority of an institution and its internal loyalty may incapacitate later courts from seeing and correcting the serious inadequacies or errors committed by a previous court if the belittling, rationalization, or even cover-ups had gone too far. The risk of miscarriage of justice by these mechanisms, Eskeland argued, was well known to the Norwegian legal community by Krarup's (1996) study of such mechanisms in British cases of miscarriages of justice:

During the assessment of the motion for retrial in 1973-1976 it was clear to anyone having the ability and will to study the case in an unprejudiced way that the adjudication of the evidence in 1958 suffered from serious weaknesses. All these weaknesses were interpreted away. In 2001, after professor Senn [the expert-witness on the bitemark of the defense] and three other prominent forensic odontologists from USA had broken down the myth that the bitemark connected Torgersen to the murder, this was obvious. But not even the Appeals Committee of the Supreme Court was able to rid itself from this mental force. (Eskeland 2005:88)

In addition Eskeland (2005) saw to six other possible sources of miscarriages of justice relevant to the Torgersen-case:

1. A court may give undue weight to witness statements: A witness, despite being truthful, may still be unreliable because of misperception due to sense-inaccuracy or interpretation (citing four studies of witness-behaviour and incorrect court decisions)
2. A court may be recommended unsound forensic evidence by experts not really being experts due to lack of experience or competence but having a high status

3. A court who is mislead to believe the certainty of actually uncertain forensic evidence may underestimate the true evidential value of witness-statements countering the forensic evidence;
4. A court may uncritically trust that the police and the prosecutor present all the evidence in the case as obliged by law — both the evidence for and the evidence against the accused (citing *The Norwegian Criminal Procedure Act 1981/2006*, sections 166, 168, 226 and actual cases where evidence had been either conveniently left out, wilfully left out, or forged)
5. A court may uncritically trust that the police and the prosecution, during the investigative phase, have actually eliminated other possible suspects (citing actual cases where this had not been the case);
6. A court may be led by a judge who has little ability or will to admit that a wrong has been committed. (Eskeland 2005:91-95)

In the Norwegian legal system a jury is set to decide the issue of guilt in cases like the Torgersen-case. Before 2010, the jury was not required to justify its decision and the Supreme Court had in 1999 decided that the fact that the issue of guilt was decided by a jury should not constitute a reason for reopening of a case. Torgersen's defence counsel agreed that the jury not being obliged to justify its decision while at the same time being the only agent with the direct access to the *best* evidence — by being the first hand witnesses of the actual presentation of both the witness-statements and the forensic evidence — makes it difficult to assess whether it actually had weighed the evidence correctly. Nevertheless, they argued, it is possible to assess the *premises* of the evidence presented to the jury: The assessment of these premises in the Torgersen-case would demonstrate that the means of evidence could not provide sufficient reasons for the jury's conclusion (Eskeland 2005:98). And finally, the counsel agreed that the principle of direct and immediate proof — that oral testimonies of both lay witnesses and experts' evidence are heard and observed directly by the jury is better than if the evidence is represented by someone or by text — did sometimes enhance the appropriate assessment of the evidence. But they argued that this was not relevant to the critical issues in the Torgersen-case: The forensic items in question still existed in good condition; the witness-statements in question exist in written form in the police transcripts as do the expert-reports; and, not the least, there exist methods today which were not available in 1958 which counter the loss of information caused by the time passed (Eskeland 2005:99-101).

The counsel's claim that the successive courts' mode of assessing the evidence had been built on insufficient premises and thus exemplified a flawed kind of reasoning drew support from the scientific community. The following article (published in a newspaper read by the cultural elite in Oslo) by a well known and respected professor of social science captured an important part of the defence counsel's argument:

The approach used by the [court-experts] deviates from what is recommended by methodology. When analysts are mandated to classify a material, and particularly when this involves elements of judgment, the analysts should not know the hypothesis preferred by those mandating. Knowledge of this preference may bias the analysts. Put on edge, the approach used in this case reminds of a situation in which a witness is presented with the suspect and asked if they agree with the police that this is the guilty one. [...] The [court-experts'] conclusion that it is very likely that Torgersen is the true biter can only be supported by knowledge about how many people were in that area of Oslo at the time of the event and who had teeth which could have made similar marks. If we as an example assume that it was 10 such persons, including Torgersen, the probability that Torgersen is the biter is one in ten — 10 per cent. If the number of possible biters is 100 the probability is reduced to one per cent — if the information included is only that of dental properties. If other information is included, say, about alibi, the number of possible candidates becomes smaller. If having reduced the number of possible candidates to three, the probability of any of the candidates of not being the biter is still larger than the probability of being the biter.

To conclude on the basis of odontological data that it is very probable, i.e. more than 50 per cent chance, that Torgersen is the true biter is the same as to conclude that there was probably no other person with teeth like Torgersen who could have made such a bitemark. This is a conclusion which may not be drawn without reliable information about the dental state of men in the Oslo-area in 1958. When such information do not exist, as is admitted by the [court-experts], one can from elementary principles of scientific inferences conclude that the [court-experts'] conclusion is not sound. (Hellevik, O. *Scientifically doubtful conclusions* Dagbladet 2000, 28.June, in Eskeland 2000; Vol. IV:179)

The article comments on the basis for the bitemark-evidence, but the same kind of unsound reasoning was claimed for the other forensic evidence as well.

Torgersen's counsel claimed that if each of the forensic means of evidence is insufficient they cannot together form a sufficient premise for the conclusion:

In a criminal case the whole body of evidence must be assessed. That means that one must interpret all the evidence in connection and decide whether they are compatible with the defendant being the offender and to which probability. More precisely it must be correct to proceed in the following way:

- (1) If there exists one or several pieces evidence which each separately excludes the possibility that the defendant is the offender and if the other evidence do not with certainty (beyond reasonable doubt) demonstrate that the defendant is the offender, there exists sufficient reason to conclude that the defendant is not the offender.
- (2) If there does not exist evidence excluding the defendant as the offender and the evidence in total makes it more probable than not that the defendant is not the offender, there exists sufficient reason to conclude that he is not the offender.
- (3) If the evidence in total suggests that it is more probable that the defendant is the offender, but if there nevertheless exists reasonable doubt that this is true then there exists sufficient reason to conclude that the defendant is not the offender. This follows from the rule of burden of evidence in criminal cases, which is to ensure that reasonable doubt goes in the favour of the defendant in the form of acquittal. This rule must in general also apply when assessing a case for reopening.
- (4) Only if all the evidence in total suggests that it is approximately certain (beyond reasonable doubt) that the defendant is the offender does reason exist to conclude that the defendant is the offender.

Which conclusion the total evidence should lead to with respect to the probability that the defendant is the offender may often create doubt because doubt may exist with respect to any one of the pieces of evidence. But some types of evidence are often considered more secure than other. These will, then, in the assessment of the overall evidence be given more weight than ("overrun") other evidence. (Eskeland 2005:113-115)

But Torgersen and his counsel were not able to convince the judges of the Appeals Committee of the Supreme Court — who sustained the Court of Appeals decision to reject the motion by High Court Ruling of 28. November 2001.

Eskeland (2005), the motion for review addressed to the Review Commission argued that the Torgersen-case is a rare case of exception where the courts have delivered the wrong decisions in total five times:

However, it is important to underscore that The Review Commission is

to assess a totally different picture of evidence than the courts had available both during 1973-1976 and during 1997-2001. It is sufficient to refer to the fact that nothing is left of the technical [forensic] evidence. The Review Commission is therefore not to adjudicate the earlier interpretations of the evidential material in the form as it then existed. The Review Commission's task is to draw the necessary consequence of what we today know with certainty: The three [sets of] technical [forensic] evidence does not connect Torgersen to the murder. Substantially the task is therefore simple. The law cannot of course authorize denying retrial when the main evidence in the case are no longer valid. Psychologically, however, it must be acknowledged that the task may be difficult. (Eskeland 2005:85-86)

The defence counsel argued that both sections 391, 1 and 3 and section 392 of The Criminal Procedure Act (chapter 27. Reopening a case) were fulfilled. Section 391, 1, was allegedly fulfilled by the following claims:

- One forensic odontological expert witness intentionally lied when testifying about the bite-mark during the trial;
- one witness intentionally lied during the trial;
- the prosecutor intentionally withheld crucial information from two witnesses; and
- the amount and kind of faeces used to connect Torgersen to the crime scene was manipulated by the expert scientist. (Eskeland 2005:80-81);

And it argued that both Section 391, 3 and Section 392, second part, was fulfilled. The following set of claims is only a selection of the themes actually claimed — the set most thoroughly treated by the Review Commission (2006) and containing claims relevant to this dissertation.

Firstly, there exist, in 2005, several pieces of exclusionary evidence. By exclusionary evidence we understand evidence which by its nature is not compatible with Torgersen being the perpetrator and that it is a high degree of certainty that the evidence is correctly interpreted. Both conditions must be satisfied and is satisfied according to the following evidence:

1. The bitemark excludes that Torgersen can be the perpetrator. This is new.
2. The time of death — which was after 23.30, most likely ca. 01.00 — excludes that Torgersen can be the perpetrator. This is new.
3. The fire was initiated after Torgersen had been arrested by the police. This excludes that Torgersen can have been the perpetrator. This is new

4. Absence of traces on Torgersen compared to traces on the crime scene (blood, soil and dirt, faeces (clothing nr.1), textile fibre, hair, fingerprints, building material) excludes that Torgersen can have been the perpetrator. This is new.
5. Torgersen has an alibi. Torgersen's mother and sister witnessed truly about the time on which Torgersen was at home and that he was together with a woman. Her name was Gerd Kristiansen. The alibi excludes that Torgersen can have been the perpetrator. This is new.

Secondly, there exist, a series of conditions which do not connect Torgersen to the murder:

6. It is most likely that Torgersen could not have had time to meet Rigmor Johnson when she was on her way home just before 23.00 o'clock. This is new.
7. The faeces-evidence does not connect Torgersen to the murder. This is new.
8. The spruce needle-evidence does not connect Torgersen to the murder. This is new.

[...] There no longer exists any evidence which connects Torgersen to the murder. This is how it necessarily must be when Torgersen is innocent. Most of the interpretations of the evidence are certain to such an extent that another reasonable interpretation cannot be claimed. To illustrate this, we will briefly demonstrate how the three pieces of forensic evidence was assessed in 1958 and their status in 2005 [I will limit to the bitemark evidence. The same kind of argument applies to the two other pieces of evidence]:

The bitemark evidence: All the experts to today, including the Norwegian Board of Forensic Medicine, with the exception of professor [ontology] Tore Solheim [footnote 70: "Solheim's view cannot be taken seriously. See section 9.2 above and chapter 8, section 7"] agree that the bitemark on Rigmor Johnsen's breast is not identical to Torgersen's teeth. All the experts today, including The [Norwegian] Board of Forensic Medicine, with the exception of professor Tore Solheim [footnote 71: "See previous note"], agree that there is no disciplinary basis on which to conclude that there is a probability that the bitemark connects Torgersen to the murder. This includes the British experts [MacDonald and Whittaker, the court-appointed experts, see chapter 5], who openly acknowledges that they have no disciplinary basis for their conclusion "very likely". The same applies for the Supreme Court's Appeals Committee in 2001 (Supreme Court Decision 2001). In 1958 the bitemark was presented as identical to Torgersens teeth and the evidence was perceived as an almost certain evidence that Torgersen was guilty. (Ekeland 2005:76-78)

But the Review Commission was not convinced: 8 December 2006 it rejected review of the case by concluding that the conditions required by the

sections 391 and/or 392 in the Criminal Procedures Act were not met by the case (Review Commission 2000). Nothing new was seen added to the motion which had not been considered several times by previous courts and latest by the Supreme Court in 2001.

The Review Commission's arguments concerning the bitemark-means and legal evidence and proof in the Norwegian legal context are presented in an addendum to chapter 7.

# Chapter 6

## The first decision about the bitemark-means in the Torgersen-case

The Torgersen-case presents a series of crime investigative decisions about the basic, causal-logical, value of a *bitemark-means*: A suspected human bitemark observed on the victim was repeatedly assessed and decided, by successive investigators and forensic bitemark-experts, to be positively relevant to one or more of the legal indictments. The final degree of relevance — having also accounted for information about situational, motivational, victim-profile, etc. characteristics — was found to be strong enough to warrant a separate bitemark-means of evidence.

In this and the next chapter I will analyse the justifications provided for the first decision about the bitemark-means in the Torgersen-case. I will restrict to the basic decision — that the bitemark-means was/is basically (causal-logical) positively relevant to one of the indictments (I will thus not analyse the further decision, about the strength of this positive relevance). The question of these two chapters is:

Were the series of crime investigative decisions about the relevance of the bitemark-means in the Norwegian Torgersen-case evidence-based to the standard of Premise 1a in this dissertation?

Recall Premise 1a:

**Premise 1a. A basic standard of evidence-basis for crime-investigative decisions**

A decision about the basic causal mechanism of a crime event is *evidence-based* if all the reference-groups and -terms causally and logically necessary for the decision are explicit and unequivocal and (a) enable person-independent assessment of the probabilities and likelihoods of the events involved and (b) enable person-independent assessment of the risk of deciding wrongly about the causal mechanism — thereby contributing to (i) the conviction of a true innocent person or the acquittal of a true responsible person; (ii) the reduction of resources available to other cases; (iii) the public losing trust and confidence in the crime investigative services and the legal institution.

In this chapter I concentrate on the first decision — the decision made in 1958. In the first section I deduce the *logical* consequences of the bitemark-means in the case the indictment(s) in the case is(are) true. This logical structure will be the frame of reference when I in the next sections identify information relevant for assessing the above question.

## 6.1 The logical structure of the bitemark-means

As we saw in the previous chapter, the legal agents on the Torgersen-case decided that the bitemark-means was a necessary means of evidence for proving the indictments to the legal standard required. Then they also accepted that the *causal-logical condition* of the bitemark-means was sufficiently certain.

A bitemark-means of evidence, like any means of evidence, need to prove a series of different *kinds* of conditions. In the first chapter of this dissertation I argued that legal arguments and involves analyses about positive and normative aspects or properties; foundational/simple and derived/complex properties; as well as legal and a-legal properties. The *causal-logical condition* exists for a means of evidence if the positive properties of the foundational kind implied by the means of evidence are certain — in terms of accuracy, precision/unambiguity, objectivity and impartiality — to the standard required in light of the consequences. This condition caters mainly to epistemic needs. Other conditions will cater to contextual, situational, social, and emotional needs. Both kinds of needs are, as claimed by Premise 3 (Chapter 1) for this dissertation, necessary for people when forming confidence and trust in claims and decisions.

A *causal-logical condition* exist for a bitemark-means of evidence if

- a. the **causal agent** (the **person**) identified in both the indictment and the bitemark-means existed,
- b. the **causal object** necessary for the act identified in the bitemark-means exists,
- c. the **effect-objects** necessary for both the acts of the indictment and the means of evidence exist; and
- d. the existences of a., b., and c. **occurred in the intervals of time and space specified in the indictment(s).**

The causal-logical condition of a bitemark-means of evidence (as for any means of evidence) is thus a necessary but not a sufficient condition for the indictment in question.

In this and the next chapter the causal-logical condition of the bitemark-means in the Torgersen-case is implied by the individuals (human or other, physical or mental) and their relationships specified in the claims or propositions representing the indictment(s) and the bitemark-means. In the Torgersen-case there were several indictments, but only two are directly relevant to the bitemark-means. I collapse the two as they have the same causal-logical condition. The **indictment-proposition** of the Torgersen-case will be specified and denoted as follows:

*PC:* "The suspect is the causal agent of the victim's lethal/rape injuries which occurred between 11.00 and 11.30 in Skippergata 6b, Oslo."

By this proposition the crime investigators claimed that the suspect was the true causal agent of the mechanism which caused the effects observed — the legally relevant such effects being the lethal/rape injuries of the victim. In the remaining analyses I will hold the following assumptions:

- The victim was correctly identified;
- the *time-interval* specified in the indictment-proposition was correct;
- the *space* specified in the indictment-proposition was correct;
- the lethal/rape-injuries were correctly diagnosed and were the true cause of death;

- the decision that there was only one human causal agent other than the victim present at the time and place specified by the indictment-proposition was correct;
- the suspect was correctly identified; and
- the decision-agents (the bitemark-experts, the forensic examiner, and the crime-investigator) were informed about the purpose of the diagnoses and the investigative decisions; were sufficiently trained/experienced; had accurate senses and normal and predictable reasoning-faculties (logical, cognitive, and emotional), and were truthful.

The crime investigators in the Torgersen-case accepted the expert's recommendation that the skinmark on the left breast on the victim was a human adult bitemark. They also accepted the expert's recommendation that the suspect's biting-mechanism was the most likely causal object of the bitemark and that the biting had occurred during the same time interval specified for the lethal/rape injuries. The investigators thus believed that the bitemark connected the suspect to the victim and to the time-interval of the lethal/rape-injuries — that it could be used as a means of evidence when arguing for the truth of the indictment(s). The causal-logical condition of the *bitemark-means* will be referred to as the **bitemark-proposition** and specified and denoted as follows:

*BM*: "The suspect is the causal agent of the bitemark observed on the left breast of the victim which occurred between 11.00 and 11.30 in Skippergata 6b, Oslo."

In the following I will first deduce the main logical implications of *PC* and *BM*. I will, secondly, suggest an inductive structure for practical situation in which the conditions are uncertain.

### 6.1.1 The logical consequences of *PC* and *BM*

The strictest logical standard possible is that for deductive arguments, namely validity. This standard may be exploited analytically in practical problems: Assuming that both the claims of *PC* and *BM* are true, then the lethal/rape injuries and bitemark both occurred by necessary consequence and explains, deterministically, why they are observable by us. But what are the simpler propositions involved if *BM* are assumed to be true? These propositions may be called diagnostic criteria or, in the legal context, conditions which must be true for *BM* to be true. I have already assumed the

truth of some of these conditions — those of time and place, the identity of the victim, etc. There are four basic and logically necessary conditions involved:

1. The skinmark on the victim must be a bitemark and not something else;
2. the suspect's biting-mechanism and not someone else's biting-mechanism must be the causal object of the bitemark;
3. the bitemark must have occurred simultaneously with the lethal/rape-injuries and not during an event irrelevant to these injuries; and
4. the analytical norms and heuristics used by the decision-makers on the case must be agreed to be conducive and not harmful to the penultimate (crime-investigative) and the ultimate (legal) purposes of the decision.

Each of these conditions rests on further conditions. The second basic condition above, for example, requires that the biting-mechanism and the bitemark are similar in a sense specific enough to exclude all biting-mechanisms but the suspect's, a kind of similarity requiring expert-knowledge of a particular kind, etc. The basic conditions (and their sub-conditions) of a true bitemark-proposition will be specified and denoted as follows:

*BM1:* "The suspect's biting-mechanism is the causal object of the bitemark";

*BM1.1:* "The suspect's biting mechanism's joint state on bitemark-index1 is compatible with the bitemark's joint state on bitemark-index2";

"Bitemark-index2" refers to the set of characteristics observed of the bitemark and decided by the expert to be relevant for diagnosing the causal object of the bitemark; "bitemark-index1" refers to the set of corresponding or correlated characteristics of the suspect's biting-mechanism

*BM1.11:* "The suspect's biting-mechanism state on bitemark-index1 is *bmi1*";

*bmi1* denotes the biting-mechanism's joint state or *profile* on bitemark-index1

*BM1.12:* "The bitemark's state on bitemark-index2 is *bmi2*";

*bmi2* denotes the bitemark's joint state or *profile* on bitemark-index2

*BM2:* "The bitemark occurred simultaneously with the lethal and the rape injuries";

*BM2.1:* "The bitemark's state on the time-index is equal to the lethal/rape injuries' state on the time-index";

"Time-index" refers to the set of characteristics observed of skin-injuries and decided by the expert to be relevant for diagnosing the time of occurrence of the bitemark

*BM2.11:* "The lethal/rape-injuries' state on the time index is *t1*";

*t1* denotes the lethal/rape-injuries' joint state or *profile* on the time-index

*BM2.12:* "The bitemark's state on the time-index is *t2*";

*t2* denotes the bitemark's joint state or *profile* on the time-index

*BM3:* "The analytical norms and heuristics are used in this case are agreed to be conducive to the penultimate (crime investigative) and the ultimate (legal) purposes of the decision";

*BM3.1:* "The norms of inference (epistemological and methodological) are agreed to be conducive to those purposes";

*BM3.2:* "The profiling instruments (set of forensic markers) are agreed to be conducive to those purposes";

*BM3.3:* "The technical instruments (observational techniques and aids) are agreed to be conducive to those purposes";

*BM4:* "The skinmark is a bitemark caused by a human adult biting-mechanism";

*BM4.1:* "The causal object of the skinmark is a human adult biting-mechanism";

*BM4.11* "The skinmark has an external cause"

*BM4.12* "The skinmark is a delimited area of abnormal epidermal structure"

*BM4.2:* "The causal mechanism is biting — teeth onto skin (not skin onto teeth)";

Figure 6.1 might assist the perception of these logical consequences of *PC* and *BM* were they to be true.

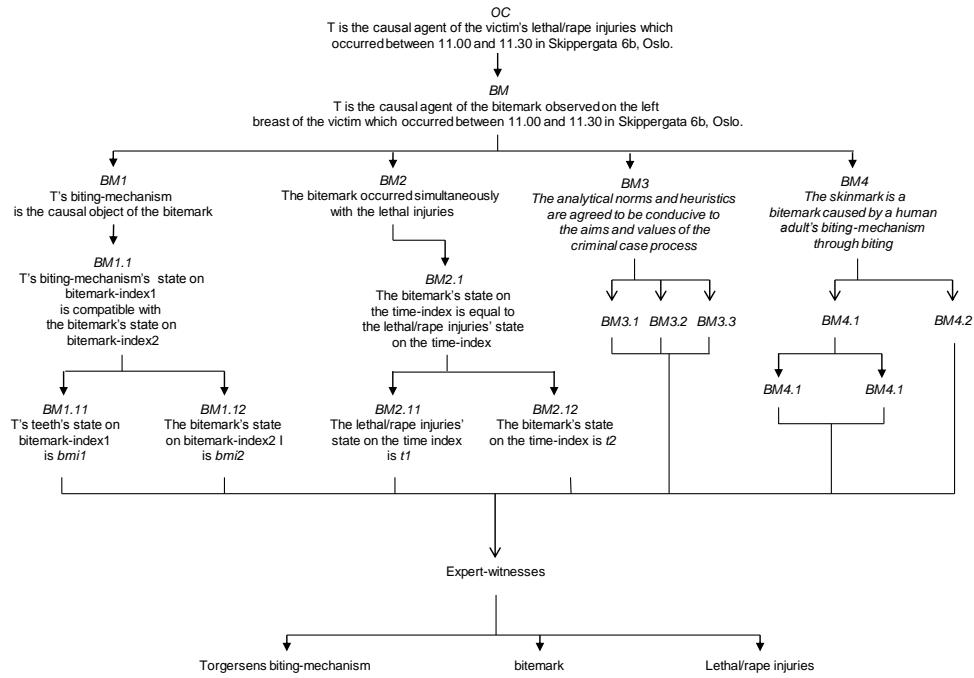


Figure 6.1: A deductive structure of the physical conditions of the bitemark-means. An arrow signifies that the two propositions involved are logically (or causally) related; and the direction of the arrow signifies the direction of the transference of the justification. Two propositions connected via an arrow will have the following interpretation: "If the proposition at the beginning of the arrow is true then the proposition at the arrowhead will be true as well."

We may turn the argument on its head and see *BM1* through *BM4* as premises for the conclusion, *BM*: *all* must be true for *BM* to be true. If the biting-mechanism is by absolute necessity connected to the bitemark then this by absolute necessity connects *the suspect* to the bitemark (via the assumption that he is the only agent which motioned his own biting-mechanism). This is necessary for *BM*. But this condition alone is not sufficient, because the suspect could have made the bitemark during another event irrelevant to the event involving the lethal injuries, because the human bitemark could be a misclassification of the skinmark (it could be an animal bitemark, caused by a tooth-like object, etc.), or because the analytical norms

or technical heuristics are not agreed to be conducive to the purposes of the decision. We could do the same exercise for the sub-conditions. All the conditions are needed, no-one is alone sufficient. We thus have two chains of implications continuing down to the forensic items observed and to the persons making the observations.

### 6.1.2 An inductive structure of the physical aspects of the bitemark-means

The standard of validity connected to deductive arguments is only a heuristic in our situation of assessing an empirical means of evidence. For such arguments we instead require *soundness*. As we saw in chapter two of this dissertation, the standard of soundness is not precise: Any premise in a complex inductive argument should be *relevant* for the conclusion, relevance existing if the premise *changes* the certainty of the conclusion. But one may not say anything general about the *degree* of change required. This depends on the other premises and *their* degree of relevance, as well as on the content of the argument and the context in which the argument is presented.

In the Torgersen-case, the bitemark-proposition could thus only be a means of evidence if it was *relevant* to the indictment-proposition in the restricted sense of it being able to reduce the uncertainty of the indictment-proposition. In this dissertation I will only assess the decision that the bitemark-proposition was relevant to the indictment-proposition. I will *not* assess whether that relevance was of a sufficient degree. That would have required similar assessments of all the other means of evidence in the case as well — legal, forensic, and lay-evidence. This was decided to be beyond the scope of this Ph.D.

To obtain an inductive structure of physical conditions of the bitemark-means we need to change the direction of the arrows and rephrase the propositions so that they need not be true or certain, but only likely. Figure 6.2 shows the inductive structure of the bitemark- and the indictment-propositions.

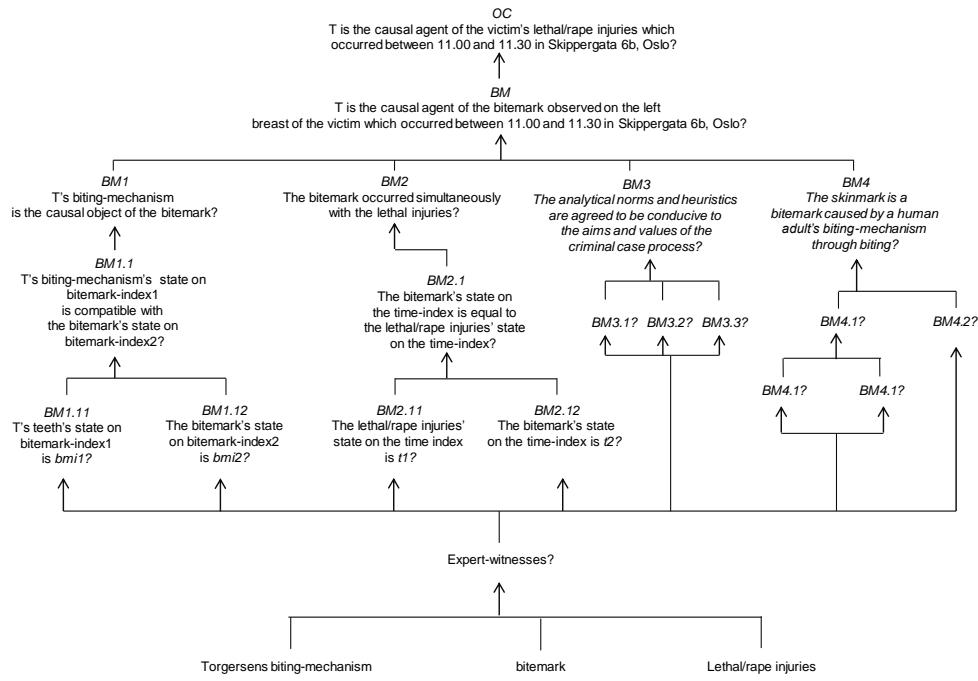


Figure 6.2: An inductive structure of the physical conditions of the bitemark-means. An arrow signifies that the two propositions involved are logically (or causally) related; and the direction of the arrow signifies the direction of the transference of the justification. Two propositions connected via an arrow will have the following interpretation: "If the proposition at the beginning of the arrow is sufficiently certain then the proposition at the arrowhead has uncertainty changed (reduced or increased, depending on the nature of the relationship between the two propositions).

The above is just the logical structure of the relationship between the bitmark-proposition and the indictment-proposition when the former is *assumed* to be relevant for the latter. Now we must attend to the substantial or material *content* of that structure. The logical structure is a necessary element of the argument — analogue to the basic engineering structure of a bridge or a building which ensures that the bridge does not collapse when subjected to the intended use. But the engineering part is not sufficient — one also needs architecture, or the tailoring of the content of the structure to the needs of the situation. So: What was the *content* of the first expert's

arguments, in 1957/1958? How did the expert *justify* the claim of relevance?

## 6.2 Justifying the claim that *BM* was relevant to *PC*

The police's medical examiner, who arrived at the crime scene at most 3,5 hours after the death of the victim, had both in the crime scene report and in the post-mortem report recorded observing a set of smaller marks and punctured skin around the nipple of the victim's left breast. He believed it to be a bitemark and called dentist Ferdinand Stroem.

Stroem was a practicing dentist but held a post teaching forensic dentistry at the School of odontology and was a regularly appointed forensic expert in cases of identification of dead bodies. He had no practical experience with diagnosing bite-marks. Stroem initiated his examination of the skinmark at most 10,5 hours after time of death. Stroem and the medical examiner agreed that the skinmark was a human bitemark and the examiner requested the court to appoint Stroem as the odontology-expert on this skinmark (Stroem 1958:1).

It should be noted that a Norwegian *court-appointed* forensic expert is expected to be independent of the parties, serving them both, and is (was?) obliged by law to submit a written report to the Norwegian Commission for Forensic Medicine for accreditation.<sup>12</sup> If accredited the report will get status as legal evidence in the case. Stroem's report has been translated and is included in Appendix 2 in its entirety as it is rather brief and gives an historical and practical example of forensic expert reasoning.

I was unable to find any document in Eskeland (2000) specifying the mandate of the bitemark-analysis. Nor was I able to find any information about the communication between Stroem and the crime investigator or prosecutor in charge of the case. The transcripts from the trial did refer to Stroem's testimony in court, but contained only court-administrative details. The testimony would have complemented the written report, but I am left with Stroem's written report *Bitemark examination of the murdered Rigmor Johnsen* (Stroem 1958, in Eskeland 2000; Vol. I: 1-7) as the only source of Stroem's reasoning. Stroem (1958) has no detailed information about the

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<sup>1</sup>I am not certain whether experts needed to have their reports accredited in 1958.

<sup>2</sup>See Appendix 1 for a brief overview of the Norwegian legal system

mandate of the forensic examination either. However, Stroem (1958) contain the exclusion of two other persons' biting-mechanisms so we may infer that he had been instructed to examine at least three biting-mechanisms.

### **6.2.1 *BM1 and BM4: "The suspect's biting- mechanism is the causal object of the bitemark?"***

Figures 6.3 and 6.4 shows the bitemark and the suspect's biting-mechanism:

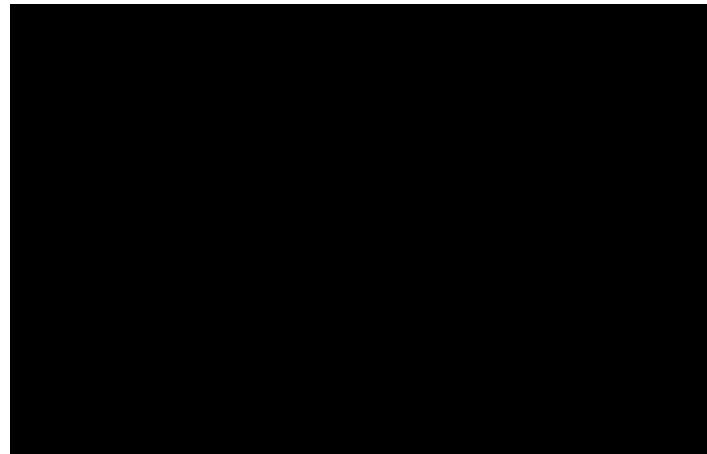


Figure 6.3: The skinmarks on RJ's left breast (photograph by Stroem (?) at the time of the medical examination). Includes Stroem's enumeration of the marks. Image is omitted due to not being able to secure permission from the copyright holder.

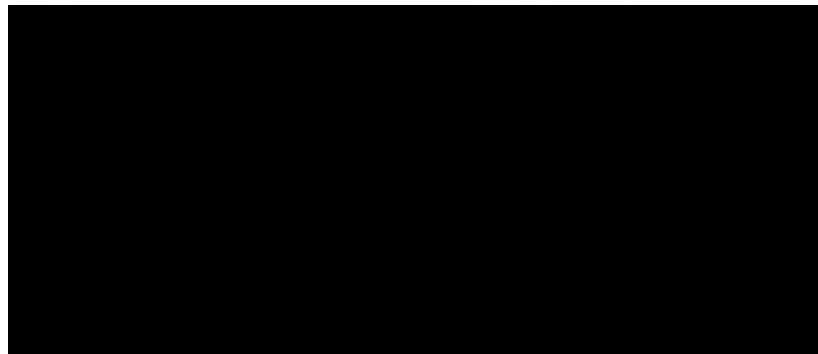


Figure 6.4: The suspect's anterior teeth (photograph by Stroem (?)) at the time of the odontological examination four months after the crime event). The numbers are in terms of FDI World Dental Organization's enumeration-system for permanent teeth (<http://www.fdiworldental.org/content/two-digit-notation>, ISO 3950.) Image is omitted due to not being able to secure permission from the copyright holder.

Before proceeding it should be noted that "bitemark-index1" and "bitemark-index2" are my terms, not Stroem (1958)'s. The indexes are just shorthand names for the sets of characteristics by which Stroem concluded about the sufficient probability of *BM1* and its consequences. "Bitemark-index2" refers to the set of characteristics by which Stroem performed his differential diagnosis concerning the causal biting-mechanism of the bitemark (given that the skinmark is a human bitemark — another set of characteristic will be required for that level of classification). The characteristics used may be color, shape, size, depth, proportion of some enzyme, etc. — any more or less refined heuristic for sorting an object into its appropriate class or subgroup. Some characteristics may be relevant for the class-determination of the causal object while others are more relevant for the differentiation within the class once this class is determined. Any characteristic used for diagnoses must be relevant — i.e. it is itself a means of evidence needing to be able to reduce the uncertainty of the diagnosis. Like any means of evidence, a characteristic will be more or less efficient — have more or less differentiating or *discriminatory power*.

What is here said about "bitemark-index2" is also relevant for "bitemark-index1". The latter is then referring to the set of characteristics used for differentiating between increasingly smaller subgroups of biting-mechanisms. The characteristics of "bitemark-index1" are assumed to correlate or co-vary with those of "bitemark-index2", but cannot do so perfectly. The mesiodistal length of the cutting edge of a tooth or a rotational pattern of a given set of teeth cannot be expected to record itself perfectly in the skin bitten because certain mechanisms will intervene during the biting-process: The mobility of the teeth and the jaw, the force and direction of the biting, and the visco-elastic properties of the skin will intervene to determine the symptoms observable of the bitemark. The profile of a biting-mechanism is thus not transferred to the bitemark on the skin: The profile of a bitemark on human skin after the biting has ceased can thus only be an indirect sign of the profile of the causal biting-mechanism.

Now we may return to Strom (1958)'s justification for recommending that *BM1* was sufficiently justified in the Torgersen-case. I will proceed by the order in which Stroem (1958) presents the information (which does not necessarily follow the logical structure of my figures 6.1 and 6.2). First he offers a partial classification of the bitemark (*BM1.12* in figure 6.2), then the classification of the suspect's biting-mechanism (*BM1.11* in figure 6.2), thirdly he re-examines the bitemark and compares the two items (completing

*BM1.12* and *BM1.1*), and, finally, Stroem (1958) concludes on the certainty of the claim of *BM1*.

### **1. The bitemark has state *bmi2* on the Stroem (1958)'s bitemark-index2? (*BM4* and *BM1.12*)**

Stroem (1958) claimed to see a human bitemark on the left breast of the victim and that it had certain states on a select set of characteristics. How does Strom (1958) justify that the skinmark is a human bitemark?

The term "bitemark" has a clear intension and extension in the Norwegian language. It refers to marks made by animal or human teeth through *biting*. Marks resulting from the process in which the object impacted onto teeth would not be called a bitemark but *teethmarks*. At the beginning of the report Stroem states that

At 09.00 am 7-12.1957 [the medical examiner] informed that [...] [a] bitemark appeared visible on one of the victim's breasts [...].

I could immediately conclude the explicit presence of marks from biting in the left breast, 3 of the marks were from the upper jaw and 3 to 4 from the lower jaw. It must be assumed that it was the front and right side teeth that had been operant during the biting. (Stroem 1958:1)

Stroem (1958) then numbers the individual marks (see figure 3 above) and describes the change to the epidermal surface-structure:

**Bitemark nr.1:** Biting through the skin, upper jaw

**Bitemark nr.2:** Biting through the skin, upper jaw

**Bitemark nr.3:** Biting through the skin, upper jaw

**Bitemark nr.4:** Biting through the skin, lower jaw

**Bitemark nr.5:** Biting through the skin lower jaw

**Bitemark nr.6:** Impression, no blood assembled under the mark, lower jaw

**Bitemark nr.7:** Possible impression, no blood assembled under the mark, lower jaw

Bleeding from the bite-wounds could not be seen, neither blood-assembling under the marks. (Stroem 1958:2)

This is the justification offered for the claim that the skinmark is a human bitemark (condition *BM4* in the above figures 6.1 and 6.2). Stroem appeals to some characteristics which could be relevant for the sub-condition *BM4.111* but generally the differential diagnosis from skinmark to human bitemark is by declaration and by pointing at the skinmark and at another witness declaring the same.

Nobody in the Torgersen-case ever questioned that the bitemark was a human bitemark. But the later experts came to disagree on the existence of two submarks: Stroem (1958), with primary objects but poorer aids for observation, suggested a possible mark 7. None of the later experts claimed the existence of this mark. But the modern court-appointed experts were to claim a possible mark 4a, in the position between Stroem's mark nr. 4 and 5. Stroem did not comment on the reason for the space which was agreed to exist here; the modern court-appointed experts argued a weak almost invisible imprint compatible with having been made by the suspect's lower right side front tooth; and the expert-witnesses for the defence counsel argued no imprint, which, they argued, could only be compatible with having been made by a biting-mechanism having no lower right side front tooth — thus excluding the suspect's biting-mechanism.

Stroem (1958) thus implicitly decided that the causal object of the skin-mark was not by animal teeth or tooth-like objects, and not by skin impacting onto teeth. None of these possibilities became issues in the Torgersen-case, but misdiagnosis at this diagnostic level is not unheard of in bitemark-cases. Bruising initially diagnosed as bitemarks has later been rediagnosed after discovering that the more likely cause was animal teeth, defibrillator-pads, bottle-tops, vacuum-pipes, or other round sharp objects (Grey 1989, Kerry et al. 1990, and James and Cirillo 2004). Hunt (2007) stressed that using the shape of the bruise as a single marker for diagnosing causal object and mechanism is risky and pointed particularly to such risk in bitemark-cases. The direction of the causal process of the mark-production is also generally relevant to the crime investigator, even if it may have seemed less relevant in the Torgersen-case. The differentiation between the mechanism behind bitemarks and that of teethmarks will require justification by motivational as well as odontological markers. In this dissertation I do not consider such conditions — only the physical ones as these are used by forensic odontologists. Yet Stroem nevertheless diagnosed the bitemark as of a particular motivational subgroup:

The bite performed is not done in order to bite off a piece, but is a so called pleasure bite, combined with sucking on the nipple of the breast. (Stroem 1958:4)

Stroem did not justify how he came to that diagnosis either. Nobody questioned Stroem's opinion about the motive for the biting.

Having decided that the skinmark was a bitemark caused by human teeth

through biting (condition denoted by *BM4* in my figures 6.1 and 6.2) Stroem (1958) proceeds to the claims that the individual marks were symptoms of different kinds of human teeth: Bitemarks nr. 1 through 3 were from the upper jaw and marks nr. 4 through 7 were from the lower jaw (Stroem 1958:2). He could differentiate between middle incisors, side incisors, and canine incisors as well:

It must be assumed that it was the front and right side teeth that had been operant in the biting. [...]

We see thus explicit marks from two upper jaw middle front teeth and impressions of two lower jaw front teeth. (Stroem 1958:1, 4 in Eskeland 2000; Vol. I:1, 4)

Stroem (1958) does not justify how he is able to make this differentiation either — perhaps it was the size, shapes, and the ordering of these characteristics of individual marks which made him conclude — but it is impossible to say.

The only characteristic Stroem observed with respect to the classification of the bitemark on the bitemark-index2 which may also with reasonable certainty be said to have been observed independently of any suspect biting-mechanism, is identified in terms of its corresponding teeth-characteristic — that of wear and its degree:

During my analysis the 7-12-57 I expressed to Police Constable Haukenaes that the one who performed this biting must have severely worn teeth in the lower jaw. (Stroem 1958:1)

Stroem (1958) does not specify this observation in dermatological terms. Stroem (1958) observes further characteristics of the bitemark, but these are identified only after having observed Torgersen's biting-mechanism. Then he also provides justification for why he does *not* report on the bitemark's state on standard characteristics. I will discuss these and their justification when explicating the justification for the claim of *BM1.1* below.

Stroem (1958) thus does not provide much substance or content of the justification for the decisions about conditions *BM4* and *BM1.12*. The main means of justification are *declaration*; *pointing* at the breast with the irregularity or at the representations of this forensic item (the photographs, models, etc.); and *authority* by scientific training, experience, and attestation.

The decisions about the sufficient certainty of these conditions were not challenged in 1958 — despite of the other court appointed expert on the bitemark, Waerhaug (1958), diagnosing some of the sub-marks as being from

different kinds of individual teeth (Waerhaug 1958:2). Only two of the decisions came to be challenged later: The decision about the number of sub-marks and the decisions about which kind of tooth was the cause of which individual sub-mark.

## 2. The suspect's biting-mechanism's has state *bmi1* on bitemark-index1? (BM1.11)

Stroem (1958) reports that four months passed before the suspect allowed him to examine his biting-mechanism. The purpose of the examination was to classify the suspect's biting-mechanism according to the set of characteristics (bitemark-index1) which Stroem decided in this case would be the most relevant for the decision whether he could be the cause of the bitemark. Stroem (1958) reports the biting-mechanism's states on the following characteristics:

**Characteristics of the "super-unit"** (the teeth/biting-mechanism):

- **Occlusion** (States: *Edge to edge*)
- **Positioning of teeth** (States : *Good and regular*)

**Characteristics of the "medium-unit"** (the mechanism's upper and lower jaw):

- (none mentioned)

**Characteristics of the "individual-unit"** (the mechanism's 12 anterior teeth):

- **Tooth-general** (States: *Not characteristic*)
- **Cuttingedge-adjacency** (States: *Spaced*)
- **Cuttingedge-furrowing** (States: *Characteristic, Especially explicit, present, explicitly cobshaped*)
- **Corner-general** (States: *Less characteristic*)
- **Corner-damage** (States: *Splintered*)
- **Corner-wear** (States: *Worn*)
- **Leftcorner-damage** (States: *Defect*)
- **Rightcorner-damage** (States: *Defect, Broken off*)

Not all the 12 anterior teeth were classified on all characteristics. Table 6.1 shows how the teeth and the characteristics distribute.

	Upper left side canine (23)	Upper left side front tooth (22)	Upper left middle front tooth (21)	Upper right middle front tooth (11)	Upper right side front tooth (12)	Upper right side canine (13)
<b>Tooth general</b>					not characteristic	
<b>Cutedge furrowing</b>			present, characteristic, (especially explicit?)	characteristic, (especially explicit?)		
<b>Corner general</b>						
<b>Corner damage</b>				right corner defect and broken off		
<b>Corner wear</b>						
<b>Cutedge adjacency</b>						
	Lower left side canine (33)	Lower left side front tooth (32)	Lower left middle front tooth (31)	Lower right middle front tooth (41)	Lower right side front tooth (42)	Lower right side canine (43)
<b>Tooth general</b>						not characteristic
<b>Cutedge furrowing</b>			present, characteristic, (especially explicit?)	characteristic, especially explicit, cobshaped		
<b>Corner general</b>			less characteristic	less characteristic		
<b>Corner damage</b>			splintered	splintered leftcorner defect rightcorner defect		
<b>Corner wear</b>			yes	yes		
<b>Cutedge adjacency</b>			spaced	spaced		

Table 6.1: The suspect's 12 anterior teeth in terms of the characteristics observed by Stroem (1958). Numbers in parenthesis refers to FDI World Dental Federation notation for particular teeth.

### 3. The suspect's biting-mechanism is compatible with the bitemark (BM1.1)

Having decided that the claim of *BM1.11* was sufficiently certain, Stroem proceeded to the next diagnostic level: Do the two samples "match" or not in light of the observed characteristics? This is the question implied by the condition denoted by *BM1.1* in figure 6.2. Stroem (1958) decides:

[...] I assess the bitemark in the breast of the murdered to be identical [Strom's underlining] to the teeth of the suspect. (Stroem 1958:5)

How does Stroem (1958) justify that conclusion? He states that

The teeth of suspect have a series of particular characteristics that without exception is to be found represented in the bite-traces of the murdered. (Stroem 1958:4)

— which is substantiated as follows:

The suspect's teeth have, as mentioned, a series of characteristics in the cutting edges of both the upper and lower jaws' middle front teeth. These characteristics are to be found also in the bitemarks.

**Bitemark nr.1** represents the furrow in the cutting edge of upper jaw's left middle front tooth.

**Bitemark nr.2** represents 2/3'rd of the cutting edge of upper jaw's right middle front tooth (the part towards the midline), and shows clearly the jagged front cutting edge. The part away from the midline is not bitten into the skin because it is broken off.

**Bitemark nr.3** must be from the right side front tooth, but has, as the tooth itself, no characteristics and is only partly recognised.

**Bitemark nr.4** must be from the lower jaw's right canine tooth but is without characteristics, as the tooth itself.

**Bitemark nr.5** is from right middle front tooth and is re-presented with all characteristics. Especially explicit is the cob shaped extension in the furrow.

**Bitemark nr.6** is from the left middle front tooth and re-presents all the tooth's characteristics, especially prominent is the straight furrow.

**The space** between the two middle front teeth's cutting edges in the lower jaw of (earlier mentioned), is clearly present in the bitemark. (Stroem 1958:4-5)

The above claims and their justifications are then the justification provided by Stroem (1958) when he concluded that it was sufficiently certain that the suspect's biting-mechanism is the most likely cause of the bitemark:

The teeth of suspect have a series of particular characteristics that without exception is to be found re-presented in the bite-traces of the murdered. From a scientific point of view it is my opinion that it is predominantly probable that the bitemark in the breast is from the suspect. (Stroem 1958:5)

Stroem had also been asked to assess and opine on the possibilities that two other individuals could be the cause of the bitemark. Stroem (1958) only states the conclusions of these analyses. Eskeland (2000) does not contain any separate reports for these analyses or signs of the existence of such. Stroem did not find these other individuals to be likely sources:

My conclusion from this examination is:

After a very thorough analysis of this material compared to with the material of the bitemarks in the murdered [victim]'s left breast, I find the deviations to be so extensive that I with certainty can exclude [L] as the one who performed this bite. (Stroem 1958:2-3)

P.S. I have also taken imprint in plastelin of [J]’s teeth Fig.19 which was without the characteristics expressed by the bitemark. (Stroem 1958:5)

Unfortunately Stroem (1958) describes the symptoms of the bitemark in terms less clear than those of the biting-mechanism — Stroem did not exploit existing dermatological terms or natural language terms which could have made the claimed connection between a given tooth and its corresponding imprint assessable by others. The characteristics used for profiling of the suspect’s teeth are reasonably clearly specified, but when the characteristics used for the profiling of the bitemark are not at all clearly specified, it is impossible for anyone to assess Stroem’s reasoning with respect to similarity between the two forensic items.

I will return to the question about the conduciveness of Stroem (1958)’s bitemark-index1 and bitemark-index2 when discussing the condition concerning the analytical norms and heuristics (denoted by *BM3* in figures 6.1 and 6.2).

### **6.2.2 ”The bitemark on the victim occurred simultaneous with the lethal/rape injuries?” (*BM2*)**

The third condition required for the bitemark-proposition to be relevant to the indictment-proposition is that the bitemark must be proven to have occurred simultaneously with the legally relevant injuries (this condition is denoted by *BM2* in figure 6.2). It does not matter much to have proven *BM1* if it cannot also be proven that the bitemark was made during the time specified — because the suspect could have made the bitemark earlier that evening during an event unrelated to the crime event. When the investigator in 1958 decided that the bitemark-proposition was positively relevant to the indictment-proposition, then this implies that the bitemark was, most likely, made during the same interval of time as that specified for the lethal/rape-injuries — i.e., between 11.00pm and 11.30pm on the night of the murder of the victim.

The question about the time-aspect of the bitemark was never an issue in the Torgersen-case, and only very few and indirect comments on it are found in Eskeland (2000): Either the legal agents agreed by some obvious signs that the bitemark did occur within the specified time interval (an agreement not found important enough for recording) — or they forgot to ask the question. It is impossible to say.

Stroem (1958), we saw above, reports about the bleeding/bruising of the sub-marks of the bitemark. These characteristics may be relevant to the question of the time of the occurrence of the bitemark: Absence of bruising/blood coupled with open incisions suggests for example that the biting occurred during or immediately after death. But Stroem (1958) does not explicitly relate these observations to the timing of the bitemark — he does not comment on the question of simultaneity at all. Stroem's unfamiliarity with dermatology may be the reason why he did not address this question. Another reason may be that he saw it to be the domain of the forensic examiner (I did not find any information about the timing of the bitemark in the examiner's reports either).

### **6.2.3 Are the analytical norms and heuristics used in this case agreed to be conducive to the penultimate and ultimate purposes of the decision about the bitemark-proposition? (BM3)**

The last condition required proven for the bitemark-proposition to become relevant to the indictment-proposition is that the analytical norms and technical heuristics are agreed among the bitemark-experts, crime investigators, and legal decision-makers to be conducive to the penultimate (crime-investigative) and ultimate (legal) purposes. The penultimate purpose is to establish the accurate and impartial truth of the bitemark-proposition. This purpose is to serve the ultimate purpose, which is to reach a solution which can be acceptable to the parties having conflicting interests and which can be respected by the public.

This condition has three sub-conditions targeting the different kinds of analytical tools used during the analyses required for the other conditions: Norms of inference (epistemological and methodological norms and rules), profiling-instruments (sets of characteristics used for diagnostic purposes), and technical instruments (technical instruments aiding observation of characteristics). I will start with Stroem (1958)'s choice of profiling-instruments, then consider his choice of observational aids, and end with his choice of norms of inference.

## 1. Was Stroem's choice of characteristics conducive to the penultimate and the ultimate purposes of the bitemark-proposition? BM3.3

**The bitemark-indexes** There are two questions concerning the conduciveness of the bitemark-indexes used for diagnosing the most likely causal biting-mechanism of the bitemark: the main question relates to the aggregated discriminatory power of the characteristics constituting in the bitemark-indexes; a second question relates to and accentuates the first question and concerns the strength of the relationship between bitemark-index1 (for classifying or profiling the suspect's biting-mechanism) and bitemark-index2 (for profiling the bitemark).

The main question concerns discriminatory power: How effective are the indexes with respect to differentiating between individuals having a given profile and individuals having another profile? Stroem (1958) provides relevant information only for two of the characteristics involved in bitemark-index1 — *occlusion-conditioned kind and degree of wear* and *ordering of the anterior teeth in a given jaw relative to a smoothed teeth-arch*:

From the models Fig.11 [present in Eskeland (2000), but omitted in Stroem (1958)] it is visible that the suspect has a so-called edge to edge bite, i.e. that the front teeth, when occluded, meet at the cutting edges. This is a deviation from the ordinary norm of upper jaw front teeth more or less covering the lower jaw front teeth. (Stroem 1958:3)

The suspect has good regularly positioned teeth [...]. (Stroem 1958:3)

In the following I will refer to these two characteristics as *wear* ("wear" when observed of a bitemark) and *rotation/position* ("rotation/position" when observed of a bitemark).

The purpose of observing specific characteristics or symptoms of individual items in the forensic or legal context is the same as that for the clinician in the health-context: To identify and narrow the set of possible mechanisms causing such manifestations — aiming ideally to be left with only one possible mechanism. In practice it is difficult to reach the ideal — because a given set of observable symptoms are but a particular and thus are but indirect and more or less distorted sign of its unobservable cause. In addition, the ability to correctly differentiate between individuals (the set of symptoms of a bitemark or a patient) having different causes depends on the diagnostician's ability to recognize ever finer cause-effect relationships. This ability depends on the diagnostician's training and experience, but also on the accumulated

knowledge via systematic studies of relevant cause-effect relationships. If a given symptom and its cause is well known (by an individual or a collective of experts and via subjective or intersubjective experience or via systematic experiments or studies of prevalence of co-variation in nature) this provides an accurate diagnosis, with few false diagnoses. If the cause-effect relationship in addition to being well known is relatively rare, then the discriminatory power achieved via this particular cause-effect relationship will be good — i.e. the certainty that the diagnosis will be correct will be high.

What would be the discriminatory power of the two kinds of symptoms or characteristics of "wear" and "rotation/position" observed by Stroem (1958)? If we may assume (1) perfect co-variation between symptom and cause for both "wear"/wear and "rotation/position"/rotation/position, (2) wear is as "deviate from the ordinary norm" as the occlusion-type is, and (3) "good and regular" refers to "within the ordinary norm" in the population in question, then the discriminatory power of "wear" will be better than "rotation/position" — because the number of possible causal biting-mechanisms having the particular kind and degree of wear observed in the case is smaller than those having the particular kind and degree of rotation/position (— if one agrees that "deviate from the normal norm" signify less than, say, 20% of the reference-population and "within the normal norm" signify more than, say 40% of that population).

But Stroem (1958) does not perform these assumptions. The only piece of information provided on the reference-population is that the suspect's kind and degree of wear is "deviate from the norm". Stroem did not say anything about the prevalence of the other characteristics or about the relationship between given cause-characteristic and its effect. Would Stroem have been able to differentiate symptoms of occlusion-caused wear from symptoms caused by other kinds and degrees of wear? These issues are not discussed by Stroem (1958). This brings us over to the related second question induced when asking about the conduciveness of Stroem (1958)'s bitemark-indexes.

This question concerns the strength of the relationship between bitemark-index1 and bitemark-index2. I have already claimed that one may not take for granted that the profile of the biting-mechanism is perfectly represented in the bitemark — due to mechanisms activated during the biting. Possible such mechanisms are

- the *force applied*;
- the *force's direction* during the biting;

- the *mobility of the teeth* when subject to this forced motion (a mobility which is conditioned by the bio-mechanical properties of the tissue-basis of the biting teeth);
- the *mobility of the skin* when subject to this load of dynamic impact (a mobility which is conditioned by the bio-mechanical properties of the human skin-area bitten);
- the *shape of the skin-area bitten*;
- the *position and direction of movement of the head and body of the biter* during biting;
- the *position and direction of movement of the body and limbs of the person bitten* during biting;

These factors will variably condition a bitemark's state on bitemark-index2. Only if the analyst accounts for these intervening mechanisms may we have confidence that bitmark-index2 is relevant to bitmark-index1 and for the forensic purposes.

Stroem (1958) touches on this issue, citing it as reason why he avoids standard measuring devices:

Due to the ball-shaped form and the plasticity of the skin of the breast a bitemark here will appear differently than that made of an apple. We do not know the position of the part of the breast that was bitten relative to the teeth-rows during the biting.

Another thing is that it does not make much sense to measure the lengths of the bitemarks in human skin as the fibers of the skin will contract the marks when biting stops and as the vaulted form of the breast makes it difficult to produce a measurement that is comparable to the suspect's teeth. (Stroem 1958:4 in Eskeland 2000; Vol.I:p.3)

But Stroem (1958) does not report on how these same mechanisms conditions the characteristics he did observe. And the report is inarticulate concerning the characteristics observed of the bitemark.

Knowledge about the mechanical properties of different types of human skin and about skin-wounds did exist for both dermatological, health-diagnostic, and forensic-diagnostic purposes and it had progressed beyond the mere descriptive and classificatory level: Particularly the study of so-called Langer's lines (refers to the natural orientation of fibers in the dermis and the epidermis) and their behaviour under impact (first described

by K. Langer in 1861 for surgical purposes) was found relevant for forensic pathological purposes as well (Spillsbury (1939), Cox (1941), Edwards et al. (1951) Camps (1952), and Hamdy et al. (1955)). This knowledge was indirectly relevant to the study of bitemarks on human skin, but any connection between dermatology and forensic bitemark-analysis is not detectable in the published literature by 1958. The existence of relevant dermatological knowledge may, I believe, not be used against Stroem in 1958: Forensic bitemark-analysis was a new domain and there was no time for an appropriate updating for the diagnostic purposes in the Torgersen-case.

A second issue related to intervening mechanisms is the change caused by time: The forensic objects may change during the time passing between the biting and the time of forensic examination: Are the observations of the characteristics of the bitemark and the biting-mechanism representative of the observations which would have been made closer in time to the actual biting? The bitemark was observed approximately 10,5 hours after the death of the victim. How does this affect the states of the characteristics of bitemark-index2? Stroem (1958) does not relate to this question and no justification is therefore given. The same question is relevant to the suspect's biting-mechanism. This was not examined until four months after the death of the victim. What kinds of change may have occurred naturally or intentionally during those four months — and how would that change the states of the characteristics of bitemark-index1? Stroem (1958) does not relate to this question either and no justification is therefore given.

Neither the question about discriminatory power of the bitemark-indexes nor the relationship between them had been studied in published papers in 1958. The number of studies on bitemarks on human skin or other surfaces was limited in most respects: The conceptual and theoretical development had in 1958 barely been initialized.

If excluding pure case-reports there were 9 published papers discussing issues connected to theory and methodological standards.<sup>3</sup>

The most directly relevant paper from this period is Berg and Schaidt (1954) who aimed to find criteria for making positive identification of biter's teeth-profile from bite-marks in foodstuff: Comparing 100 persons' diapos-

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<sup>3</sup>The review was performed mainly through UCL's library's metalib-engine (searching-terms being "bitemark", "bite-mark", "bite mark", ) and complemented by hand-searching (a) forensic, odontological, and dermatological journals, (b) the reference-lists of published papers, and the collections compiled by European and American organizations for forensic scientists and for forensic odontologists.

itively photographed teeth-imprints to a given bitemark known to be from one of the 100 persons, they noted that several superimposed exactly on one or two teeth, but only one superimposed on all teeth in a given arch of teeth. They suggested therefore that no positive identification should be made unless at least four or five adjacent marks could be observed in the bitemark. I will relate this standard to that of Stroem (1958) below. Five papers study potentially relevant teeth/biting characteristics, but were not related to bitemarks per se: Two papers study the prevalence of teeth-characteristics (teeth-positioning (Seipel 1946) and the mesiodistal crown-diameters (Moorees, 1957)); and three papers study the force of biting (Howell and Manly 1948), (Howell and Brudevold 1950), (Kydd 1956). The remaining papers are descriptions of technical heuristics (procedures of photography, instruments of observation, and materials for sample representation) and are only indirectly relevant to bitemark analysis, the aims being to enhance reliability and validity of representations of primary samples.

The available knowledge about bitemark-analysis in 1958 was thus rather poor. It provided no guidance to Stroem in his particular problem-situation; and leaves it difficult to assess whether the bitemark-indexes were conducive in terms of discriminatory power.

The poor understanding of the causal mechanism of bitemark-production and the underdeveloped set of terms for describing the dermatological effects of the characteristics of bitemark-index1 came later to create confusion with respect to the evidential value of the bitemark in relation to *BM1*. I will in the next two chapters return to these problems of justification. They will figure centrally in this dissertation's assessment of the question about the evidence-basis of crime investigative decisions about bitemark-means.

**The time-index** Given the lack of written information about the question of simultaneity between the bitemark and the legally relevant injuries in the Torgersen-case, it will be impossible to assess whether any time-index was conducive to the purposes of the decision about the bitemark-proposition. Both the condition about simultaneity and its sub-condition about the sufficient relevance or discriminatory powers of the characteristics — the *time-index* — used to assess the question about simultaneity are but implied by the acceptance of the relevance of the bitemark-proposition.

A *time-index* would contain characteristics indicating the stage of the repair-process of skin-injuries. Knowledge about the repair-process of skin-

wounds existed in 1958 and had progressed beyond the mere descriptive and organizational: Lowell et al. (1953) had studied the effects of cortisone and adrenocorticotropic hormone in bruises over time. Udenfriend et al. (1955) had studied the role of serotonin and Robertson (1957) had studied the difference between antemortem and postmortem bruises. The existence of relevant knowledge about the timing of skin-wounds may, I believe, not be used against Stroem in 1958: Forensic bitemark-analysis was a new domain, there was no time for an appropriate updating for the diagnostic purposes in the Torgersen-case, and it is possible that the forensic examiner in the Torgersen-case would be the correct address for assessing the justification of the decision about simultaneity (I did not find any such information in the examiners reports).

**2. Was Stroem's choice of observational aids conducive to the penultimate and the ultimate purposes of the bitemark- proposition? (BM3.2)**

The accuracy of an expert's assessments and decisions will, in addition to the individual's own senses and reasoning capacities, depend on the accuracy of the instruments and materials used during the analyses of the given samples. In our case, Stroem (1958) does not divulge many details about the instruments and materials used: The only instruments indicated to have been used are *stereography* and *photography*. There are no specifications of the methods applied while using these instruments, but the methods of photography involved different angling, different lighting, different scaling, and with and without a one-dimensional ruler. Stroem did not discuss the reliability of these instruments or the validity of the information resulting from the use of these instruments.

Stroem stated to have used *plaster* and *plastelin* for the imprinting and the modeling of both the skinmark and suspects' teeth. He also stated to have used a certain *preserving liquid* for the preservation of the excised breast tissue, but does not state the kind nor the specific properties of any of these materials. We know that he did not use any stabilizing mechanism when excising the breast tissue. But we do not know the excising method or who performed that procedure. What is also lacking from Stroem (1958) is information on the labeling of the primary and the secondary samples.

The only comment on reliability or validity issues connected to the intervention procedures is about the imprint obtained from the suspect's teeth:

14-4-58 I made an imprint of his teeth and let him bite into plastelin. He was helpful, and I got the best imprints. (Stroem 1958: 3, in Eskeland 2000; Vol. I:4)

No legal agent questioned the reliability of the information derived from using these instruments and this material — not in 1958 and not later. However, the incomplete identity-labeling of the secondary samples was to become an issue when the case was assessed for retrial in 1973-76 and 1997-2001 — when the experts disagreed on what ought to constitute the "best evidence".

### **3. Was Stroem's choice of norms of inference conducive to the penultimate and the ultimate purposes of the bitemark- proposition? (BM3.1)**

The last sub-condition required of the condition about analytical norms and heuristics concerns the norms of inference chosen by Stroem (1958). Stroem (1958) provides some information directly relevant to this question:

An odontological examination of a bitemark-trace compared with the suspect's teeth will, if there do not exist accordance [/agreement/similarity], imply absolute acquittal for the suspect. Differently if existence of accordance [/agreement/similarity]. In this case there will always be judgements and there should be exhibited care, if there are no details that are judged to be particularly characteristic.

The teeth of suspect have a series of particular characteristics that without exception is to be found re-presented in the bite-traces of the murdered. From a scientific point of view it is my opinion that it is predominantly probable that the bitemark in [the victim's] breast is from the suspect.

Based on my personal experience, well informed about my responsibility, I assess [/conclude] the bitemark in the breast of the murdered to be identical [Strom's underlining] to the teeth of the suspect. (Stroem 1958:5)

Stroem (1958) thus has a decision-criterion tailored to the forensic situation, a criterion different from Berg and Schaidt (1954). They suggested that no positive identification should be made unless at least four or five adjacent marks could be observed in the bitemark. Stroem (1958) recommends a positive identification based on 6 sub-marks profiled on given characteristics. That Stroem did not use Berg and Schaidt's recommendation may not necessarily be used to criticize Stroem's choice: Berg and Schaidt (1954) used a different comparison-technique than Stroem did, the study was experimental, under non-natural conditions, and it concerned bitemarks in foodstuffs, not human skin.

But Stroem (1958) has no further comment on the more general standard of inference required for this situation — i.e. for decisions in situations characterized by high and uncertain conditioning and serious consequences. He acknowledges that judgment is involved and that care should be exhibited, but does not appeal to any more specific standard of inference for the situation. And he does not appeal to the standard usually required within the scientific context. This standard assumes that all observations of real phenomena and inferences from such observations are inherently uncertain. Therefore any conclusion of consequence should be according to a given basic norm of inference to make the risk of error as small as possible: The decision-maker should always assess the probability of the observations/inferences under the possibility that the *negation* of the suspected hypothesis is true; and only if this probability is sufficiently small may he/she conclude that the observations are significant and relevant in some further sense. This norm, conserving the attention on the possibility that the suspected hypothesis could indeed be false, forces about and makes routine an explicit deliberation about the most appropriate reference-populations — an element crucial to this dissertation's notion of evidence-basis.

Stroem (1958) does not deliberate on the relevant reference population. Instead he seems to apply the standard practiced in everyday decisions — that of ***incomplete or open induction***: One has a problem, searches for possible explanations and hypotheses, suspects one explanation as more likely than the others, avoids a structured deliberation, selection, specification, and closure of the space of possibilities, and attends primarily to the likelihood of the anticipated or suspected hypothesis. This strategy is fine for everyday problems when time is limited and the consequences are not too serious. But it is less appropriate if one needs to be certain that the decisions do not bring about unwanted consequences. This need is fundamental to scientific knowledge-production, and it is the reason why scientists are obliged to adhere to the basic norm of inference described above — that of ***complete and closed induction***: One has a problem, searches for possible explanations and hypotheses, suspects one as more likely than the others, seeks *consciously* — contrary to the everyday strategy of *incomplete and open induction* — a structured deliberation, selection, specification, and closure of the space of possibilities, and attends primarily to the likelihood of the negation of the suspected hypothesis. This fundamental need to be certain that decisions do not bring about unwanted consequences, and the norm and procedures caring for this need, was well known and agreed about

in 1958, also in the Norwegian academic institutions.

Stroem was an odontologist and had been exposed to the scientific standard of inference through the obligatory courses in general as well as practical methodology. But he was a practicing odontologist and may, like many practicing professionals, have found the principles and examples of methodology-courses ill-fitting to real decision-problems that are conditioned in nonstandard ways.

Was Stroem (1958)'s choice of decision-strategy an anomaly? And how did Stroem's analysis compare to the state of the knowledge and knowledge-production on forensic bitemarks in 1958?

Professor Dr. Waerhaug was appointed as a second court-appointed expert in May 1958 and provided a written report in May 1958 (Waerhaug 1958, in Eskeland 2000, Vol.1:8-9). Waerhaug (1958) applies the same approach as Stroem (1958), both concerning the kind of characteristics observed and the inference-strategy. But unlike Stroem, he had no qualms about using standard measurements. He also diagnosed one mark differently than Stroem and did not perform the analysis completely independently of Stroem's analysis. But all in all it is possible to say that Waerhaug (1958) corroborated Stroem's solution to the problem as well as his conclusions: Waerhaug (1958) also chose to use *incomplete and open induction*.

The number of published studies on bitemarks on human skin or other surfaces was, as said above, limited in most respects. The conceptual and theoretical development had in 1958 barely been initialized: Two papers study the prevalence of characteristics of biting-mechanisms (not of bitemarks in skin) (Seipel (1946) studies teeth-positioning and Moorees (1957) studies the mesiodistal crown-diameters and three papers study the force of biting (Howell and Manly (1948), Howell and Brudevold (1950), and Kydd (1956). Five papers study potentially relevant characteristics, but were not related to bitemarks per se. And no regional forensic organization existed which could have guided Stroem concerning neither the choice of observation/analytical heuristics nor the choice of diagnostic strategy. His most important reference was most likely the standard he knew was accepted by the legal agents concerning the forensic work he had experience from, namely identification of dead bodies from teeth and dental records.

## 6.3 Was the decision about *BM* evidence-based to the standard of Premise 1a?

The crime investigator decided that the bitemark-proposition was positively relevant to the indictment-proposition. This decision was based on Stroem recommending that "[...] it is predominantly probable that the bitemark in [the victim's] breast is from the suspect" (Stroem 1958:5) — which in turn was based on Stroem finding that "[t]he teeth of suspect have a series of particular characteristics that without exception is to be found represented in the bite-traces of the murdered" and "[...] the bitemark in the breast of the murdered [is considered] to be identical [Strom's underlining] to the teeth of the suspect." (Stroem 1958:4, 5).

Was this decision evidence-based according to the standard specified in Premise 1a of this dissertation? Premise 1a in terms of the bitemark-problem is as follows:

**Premise 1a. A basic standard of evidence-basis for decisions about the basic evidential value of bitemark-means**

A decision about the evidential value of a bitemark-means is *evidence-based* if all the reference-groups and -terms causally and logically necessary for the decision are explicit and unequivocal and (a) enable person-independent assessment of the probabilities of the events involved and (b) enable person-independent assessment of the risk of deciding wrongly about the evidential value — thereby contributing to (i) the conviction of a true innocent person or the acquittal of a true responsible person; (ii) the reduction of resources available to other cases; (iii) the public losing trust and confidence in the crime investigative services and the legal institution.

We can assume that both the crime investigator and the expert both knew about and intended to contribute to the aims of the investigation and the ultimate aims of the legal processing of the case — that they had no intention to undermine these. But the information provided in the written sources is both too incomplete and too ambiguous for assessing the (a) probabilities of the events involved and (b) the risk of having decided wrongly about the

evidential value of the bitemark-means: No information at all is provided for the diagnostic criterion concerning the time of occurrence of the bitemark; the information provided for "bitemark-index1" and "bitemark-index2" (the profiling-instruments) are to a large extent implicit and those explicit are ambiguously specified; and the information provided for the reference-groups used for the decisions about the source-object, the biter, and the offender of the legally relevant acts is equally implicit or ambiguous. Even if we assume that the combined profile of the suspect's biting-mechanism was in fact rare in the population *and* highly correlated to the profile of the bitemark, there is no sign in Eskeland (2000) concerning the reference-population of possible offenders of the legally relevant act. Surely, more than one person could have been the offender and surely the investigator reflected on the nature and size of this suspect-population, but no record exists of this.

The information provided in the written sources is thus of a kind not expected if the expert's and the investigator's decisions were evidence-based to the standard of Premise 1.

But perhaps the expert and the investigator completed and specified the information orally — during the investigative phase or in their testimonies in court? That is possible. The written sources do not divulge much about this. In 2006, the experts and the investigators are required to provide the complete and unambiguous reference-groups and -terms in the written report — because these have to be accredited by The Norwegian Board of Forensic Medicine but just as much because the modern notion of legitimacy is different than in 1958: The 1958-public may have seen authority in itself as a sufficient source of legitimacy.

In light of the kinds of information provided in the written sources, the conclusion is that (a) it is more likely than not that the crime investigative decision (that the bitemark-proposition is positively relevant to the indictment-proposition) in 1958 was not evidence-based to the standard of Premise 1 of this dissertation, but that (b) Premise 1 might not be relevant for the forming of legitimacy, confidence, and trust in 1958.

It should be noted that not being evidence-based does not imply that the investigative decision about the relevance of the bitemark-proposition is incorrect: It might be correct or incorrect. Not being evidence-based means only that there are no person-independent means, in the form of information about the reference-groups and -terms, by which we can assess the justification and the reasonableness of the decision. Not providing such information in 2006 may affect the public's trust or confidence in the decision, the inves-

tigative services and/or in the legal institution. And the provision of such information will become more critical when the means of evidence are weak and when the consequences of wrong decisions are serious.

In the next chapter I move to study the information provided for the two last decisions about the relevance of the bitemark-proposition the in the Torgersen-case — to assess whether these are evidence-based to the standard of Premise 1 of this dissertation.

# Chapter 7

## The modern decisions about the bitemark-means in the Torgersen-case

In this chapter I will study the modern crime investigative decisions about the bitemark-means of the Torgersen-case. Torgersen motioned several times to have the case re-investigated and retried: One of the main arguments was that the technical forensic evidence, including the bitemark-means, was incorrect due to being logically biased (attending only to the suspected hypothesis) and that the agents of the legal community could not see this because they were contextually partial (loyal to the previous decision-makers as well as preferring the suspected hypothesis). The aim of the study is the same as in the previous chapter: Were the modern decisions about the basic evidential value of the bitemark-means evidence-based to the standard of Premise 1 in the first chapter of this dissertation?

In the first section I present the decision agents involved — the forensic experts and investigators. In the second section I explicate the reasoning of the modern investigators and the bitemark-experts — relative to the logical structure of bitemark-means suggested in the first section of the previous chapter. A third section assesses and concludes about the question of evidence-basis. In an addendum to this chapter I present the Norwegian Criminal Cases Review Commission's position on the norms and standard of reasoning with respect to forensic evidence.

## 7.1 The decision-agents involved between 1997 and 2006

In chapter five we saw that Torgersen motioned for retrial three times: First in 1973, then in 1997, and finally in 2004/2005. One of the main arguments for the motions was that the forensic means of evidence, including the bitemark-means, were incorrect due to the analytical procedure (or lack of such) used for assessing evidential value. Each time both the court and the appeal-instance decided to reject the case. None of the in total four courts saw any flaws in the analytical procedure and concluded that the bitemark-means was positively relevant to the indictments. Neither the Norwegian Criminal Cases Review Commission (hereafter **Commission**) saw any analytical flaws or any other condition required for review.

Space only permits in-depth analysis of the reasoning in the period between 1997 and 2001 — the period ending with the decision by the Appeals Committee of the Norwegian Supreme Court (hereafter **Appeals Committee**) in 2001. I will attend predominantly to the **court-appointed bitemark-experts**' reasoning towards the diagnostic decisions: The information on the *investigators*' reasoning is better for 2001-decision than for the 1958-decision, but the expert-reports are still much better than the investigative reports; and the information on the *expert-witnesses*' reasoning, while good, is incomplete with respect to the bitemark-proposition: Legally obliged only to react to the court-appointed expert's reasoning, their reports address only selected issues of the bitemark-propositions, leaving others un-commented.

The exclusion of the analysis of the reasoning behind the two decisions made in 1973-1976 and that of the Commission in 2006 is not too serious: The norms of inference of the court-appointed expert-reports are the same as in 2001; and while the experts used partly different markers due to newer technical heuristics, the discriminatory power of these markers was not better justified than the other markers used in the case. Neither diagnostic procedure nor the knowledge-basis of forensic bitemark-analysis had changed very much conceptually, theoretically, or empirically during the period between 1973 and 1997. The conclusions about the evidence-basis of the (1973-1976)-decisions and the 2006-decision were similar to that of the 1997-2001-decision, and for the same kinds of reasons. In an addendum to this chapter I present the Commission's position on the norms of inference for assessing forensic

evidence.

### 7.1.1 The court-appointed experts

Eskeland (2000), Eskeland (2005), Public Prosecution (2005) and Commission (2006) give reason to believe that there were in total 10 bitemark-experts involved between 1999 and 2006: 2 court-appointed experts (obliged to serve both parties and to provide written reports accredited by the Norwegian Board of Forensic Medicine) and 8 expert-witnesses (legally only obliged to serve the appointing part but professionally obliged to be impartial).

In August 1998 The Borgarting Court of Appeals appointed two bitemark experts: D. G. MacDonald, professor of odontology (pathology) at Glasgow Dental Hospital and School, Glasgow University, Scotland; and Dr. David K. Wittaker, university teacher in odontology (biology) and forensic odontology at the Dental Schoool, University of Wales College of Medicine. Hereafter, **MD/W**, will refer to these two experts.

Their mandate was to assist the court in assessing questions raised concerning the opinions of the 1958- and 1976-experts and to re-investigate the forensic material and provide opinion in the case (Eskeland 2000; Vol. I: 98-99) (I return to the mandate in the next section). They submitted a joint report 28.July and 3.August 1999. This report exists in Eskeland (2000: Vol. I; 123-170), but will hereafter be referred to as *MD/W (1999)*. They submitted two more reports to answer further issues: One in May 2000 as the result of the Norwegian Board of Forensic Medicine (hereafter **Board**) requesting fuller analysis of certain aspects and response to critical questions raised by the defence counsel; and one in July 2001 as the result of questions raised a Court-hearing about the bitemark evidence. These two reports will hereafter be referred to as **MD/W (2000)** and **MD/W (2001)**.<sup>1</sup>

MD/W were experienced bitemark-analysts, both concerning practical forensic analysis and academic work. I am not able to say how many cases they had each assisted on. Each had contributed to the bitemark-discourse through published papers: MD/W had, alone or with other scholars, authored 3 and 10 papers respectively. MD/W stayed on as appointed experts until the final decision in 2006. Throughout the period between 1999 and 2006 they submitted further statements in connection to several court-

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<sup>1</sup>MD/W (2000) and MD/W (2001) are represented in Eskeland 2000 Vol. III 336-375 and Vol. IV 213-273, respectively

meetings and hearings. These statements do not exist in one collection, but are scattered on several institutions with variably strict access regulations. MD/W (1999, 2000, 2001) contain their main analysis. Statements provided during court-hearings will be referred to by their occurrence in Commission (2005).

### 7.1.2 The expert-witnesses for the defence

In 1998 Torgersen and his defence counsel appointed dentist Johannesen (general practitioner), professor (human anatomy) Per Holck, and senior researcher Dr. Med. (human anatomy) Per R. Flood. None of these had any experience with forensic diagnostics, but were appointed due to expert knowledge in clinical dentistry, human skin, and instruments for observing geometric characteristics. It was the later appointed Professor David Senn (D.D.S., Diplomat of the American Board of Forensic Odontology (ABFO)) from The University of Texas Health Science Center at San Antonio, Dental School who came to represent as the main expert-witness. Senn submitted a report to the defence counsel in the 28. July and 3. august 1999. This report exists in Eskeland (2000, Vol.I pp), but will hereafter be referred to as **Senn (1999)**. Senn, similar to the court-appointed experts, submitted further statements throughout the period between 1999 and 2006 in connection with the court-meetings and the hearings. I will refer to these later statements as "Senn, in Eskeland (2000)", "Senn, in Prosecution (2005)" or "Senn, in Commission (2006)".

Senn had approximately 10 years of practice from forensic odontology, is an ABFO-diplomat, a Fellow of the American College of Dentists, a Fellow of the International College of Dentists, and a member of the American Dental Association, the Texas Dental Association, and the San Antonio District Dental Society. Since 1976 Senn had co-authored on one publication relevant to forensic bitemark analysis in international dental or forensic science journals (Senn et al. 2005). Senn was later assisted by three colleagues, also diplomats of the ABFO: Professor (DDS) Michael Bowers (Ventura California); professor (DDS) Marden E. Alder (San Antonio, Texas); and professor (DDS) Paul. G. Stimson (Houston Texas). Particularly Bowers was a strong voice in the bitemark-discourse in the period after 1976. He had authored or co-authored 17 books and papers in international journals the content of which signifies a broad interest and experience in theoretical, experimental, methodological, and forensic diagnostic aspects bitemark-analysis. Bowers,

Alder, and Stimson did only provide indirect support to Senn — they did not offer their own reports nor did they formally attest to Senn's analyses of the bitemark in the Torgersen-case.

### **7.1.3 The expert-witnesses appointed by the prosecution**

The prosecution had appointed Professor (odontology) Tore Solheim (Faculty of Dentistry, University of Oslo, Norway) as their expert-witness. As far as 2002, Solheim had published four papers on identification from teeth and dental records (Solheim et al. 1995, Solheim et al. 1995, and Solheim et al. 1992, and Solheim et al. 2002), but any experience or substantial knowledge of identification of biter from bitemarks was not signified until 2006 (Bernitz et al. 2006).

Of all the involved experts on the bitemark theme of this case it was MD/W who were originally appointed by the court and thereby had the status as court-appointed experts. They were thus by law obliged to serve both parties and to submit their written reports for accreditation by the Norwegian Board of Forensic Medicine (Board). I am unable to say whether any of the other experts received this legal status. Torgersen's counsel motioned to have Senn appointed, but I am unable to document whether the status was actually given. The status came to matter less: All the experts involved were given access to the forensic items, allowed have written reports assessed by the Norwegian Board of Forensic Medicine, and to voice their opinions during several court-hearings concerning the bitemark-theme.

### **7.1.4 The Norwegian Board of Forensic Medicine (Board)**

The Board also came to play an important role during the courts' assessment of the Torgersen-case during this period. It was requested on several occasions to deliver written statements about the experts' analyses of the bitemark. The Board is appointed by the Ministry of Justice and its main mandate is to supervise, control and accredit the analyses performed by court appointed experts in criminal cases. The Board is also a hearing body in certain cases, as it came to be in the Torgersen case. The Board's legal authority

is anchored in section 146 of the Norwegian Criminal Procedures Act.<sup>2</sup> The information about the Board's assessments and decisions is sourced by Board (1999), Board (2000), Board (2001), and Commission (2006).

### **7.1.5 The investigators in the period between 1999 and 2006**

In the period between 1997 and 2006 we get more information about the reasoning of the investigators. Particularly Commission (2006) is valuable in this respect. Five persons signed the Commission (2006): three jurists, one psychologist, and one psychiatrist. I do not know how many investigators were involved on the bitemark-means. It is also rather difficult to separate between the investigative reasoning and the legal reasoning: Some of the investigative decision-makers are the same individuals as the legal decision-makers, and the Commission (2006) does not separate between reasoning for diagnostic and penultimate factual purposes and reasoning for ultimate legal purposes.

## **7.2 The court-appointed experts' justification of *BM1* through *BM4***

It is known that both the Appeals Committee and the Commission found that the bitemark-means of the Torgersen-case was positively relevant to and necessary for the indictment(s) of the case. Figure 7.1 reminds of the basic logical structure of the bitemark-means.

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<sup>2</sup><http://www.justissekretariatene.no/en-gb/Innhold/The-Commission-for-Forensic-Medicine/>

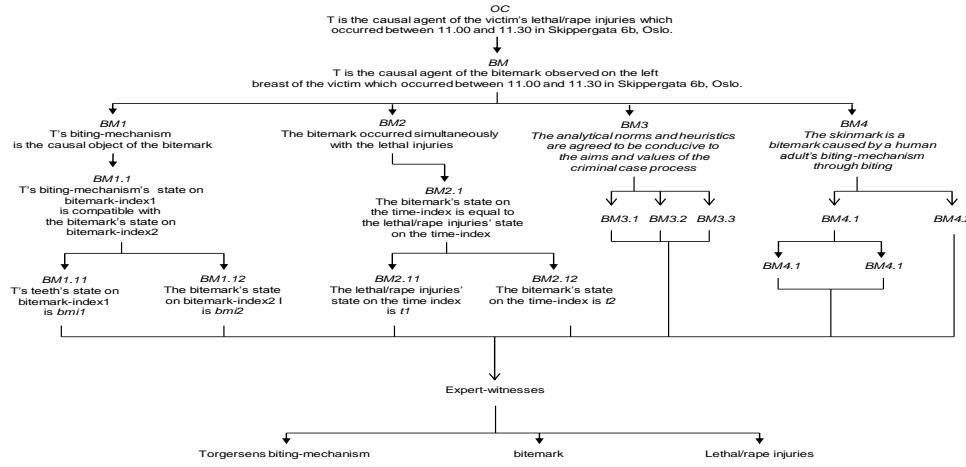


Figure 7.1: The basic logical structure if both the physical conditions, *BM* and *PC*, of the bitemark-means and the indictment(s) respectively are true. Arrows signifies transference of justification.

21. August 1998 MD/W received a letter from Borgarting Court of Appeal formally appointing them as experts on the bitemark in the Torgersen-case. Their mandate, included in the same letter, was as follows:

Your task will first and foremost be to assist in evaluating questions raised against the opinion of earlier appointed experts, in particular the statement that the perpetrator must have had one or more teeth missing and the that position of [suspect]'s teeth can rule him out as the person who left the toothmarks. [...]

It is assumed that you will give a written report to the Court of Appeals, containing your opinion in the case. You can otherwise undertake the investigations/tests you find necessary. Any questions or requests you might have to the prosecuting authority or [suspect], should be put forward to the court. (Eskeland 2000; Vol. I: 98-99)

Before I start the analysis of this question it is important to know that the forensic items available to the experts were less than ideal than that of the first expert Stroem:

- The excised breast with the skinmark;
- Photographs of the breast with the skinmark (before being excised) at the crime scene and on the autopsy-table during external examination of the deceased;

- Photographs of the breast after excision
- Imprints (plaster) of the skinmark (made by Stroem in 1957) and photographs of these imprints
- Imprints (unidentified material) of the skinmark (made by Stroem in 1957?) and photographs of these imprints
- Imprints (unidentified material) of suspect's teeth (made by Stroem in April 1958) and photographs of these
- Imprints (plastelin) of suspect's teeth (made by Stroem in April 1958) and photographs of these
- Models (unidentified material) of suspect's teeth based on the plastelin-imprints (made by Stroem in April 1958) (MD/W 1999:Appendix 1)

From now on, unless otherwise specified, "skinmark" and "bitemark" will both refer to any tangible object in the list above that represents the original skinmark on the breast as observed at post-mortem prior to excision. Likewise, "the suspect's biting-mechanism" will, unless otherwise specified, refer to any tangible object in the list above that represents the suspect's natural biting-mechanism as observed by Stroem in April 1958.

The following analysis starts with the justification provided for the claim of *BM4* and *BM1*, continues with that for the claim of *BM2*, and ends with that of the claim of *BM3*.

### **7.2.1 "Is the suspect's biting-mechanism the most likely cause of the bitemark?" (*BM4* and *BM1*)**

#### **1. "Is the skinmark a human bitemark? " (*BM4*)**

MD/W (1999) simply decides without further justification that the skinmark is a human bitemark — a mark made by human teeth through the process of biting. MD/W(1999) does not discuss the other possibilities and thereby excludes that the skinmark stemmed from causes internal to the victim, from tooth-like objects, or from animal teeth:

All [individual marks] show a mark which consists of several elements which are completely in accordance with a bitemark made by a human set of teeth. (MD/W 1999: 6).

2 The bite in [the victim]'s breast shows marks from three front teeth of the upper jaw and at least three front teeth of the lower jaw. These teeth [marks] show explicit characteristic features with respect to shape, size, and

position. In particular there exist non-normal characteristics in terms of teeth's wear. (MD/W 1999:15)

## 2. "Is the bitemark's state on bitemark-index2 *bmi2*?" (BM1.12)

Unfortunately, MD/W (1999) is just as inarticulate and imprecise about the characteristics observed of the skinmark as Stroem (1958): Existing dermatological terms for describing the skinmark are not exploited. Instead a rich variety of natural language adjectives referring to teeth is preferred. The following quotation illustrates: (MD/W (1999) adopt Stroem (1958)'s numbering of the individual marks of the skinmark).

The cutting edge on the lower jaw's left middle front tooth (mark 6) shows a narrow furrow which runs in the breadth of the cutting edge. In the bitemark this furrow appears as parallel light and dark linear areas. The light part towards the tongue is the side of the furrow which is towards the tongue. The part of the cutting edge which is towards the tongue has not made an explicit mark. The dark area towards the lip-side of the tooth is the other side of the furrow.

This is in connection with a clear delineation of the lip-side of the cutting edge. The irregularity in the cutting edge is probably caused by wear of the edge by contacting the opposite teeth in the upper jaw which has caused a loss of the hard tooth enamel and an exposition of the underlying tooth bone which is softer and which is easier lost. The cutting edge of the lower jaw's right middle front tooth show a similar wear pattern but is less marked. The furrows in the middle teeth lay in a flat angle in relation to each other and are more or less on a line. The part of the lower jaw's right front tooth which faces towards the tongue has made a more explicit mark than the part facing towards the lip. The marks from the two middle front teeth seem to be separated by a small space which may possibly signify an actual space between the teeth or a small defect of a part of the cutting edges. (MD/W 1999:7-8)

It is impossible to say why MD/W (1999) use the natural language kind of adjectives instead of existing dermatological and odontological terms. Perhaps they believed this to be better when addressing a lay audience. But no reasons are given for this choice of terms. The result is imprecision and disintegration into detail.

To make the information more manageable I had to impose broader categories and use anatomical and odontological terms wherever I felt this to be safe. I am variably happy with my choices. An example: MD/W (1999) observe that (a) "Mark 4 is a small oval mark [...]" (1999:6) and that (b)

”Mark 4 [...] is shown as a moderately pointed rounded mark” (1999:8). I translated this into claims about the sub-mark’s *shape* (being *rounded*) and *size* (being *moderately pointed*). I believe this to be reasonable, but I may be wrong. If I doubted the efficiency of the translation I chose to use the adjectives originally chosen by MD/W (1999).

MD/W (1999) report (in my terms) to have observed the following characteristics of the **secondary skinmark**.

- **Characteristics observed of the ”macro-unit” of the skinmark**

**Characteristics** (not specified) (States: *Completely in accordance with characteristics expected when causal process is biting with a human set of teeth*);

**characteristics** (not specified) (States: *Similar to characteristics expected when causal object is individual teeth*);

**Indentation-explicitness** (States: *Explicit*);

- **Characteristics observed of intermediate units of the Secondary skinmark:**

**Shape** (States: *curved; almost linear; angle; similar to the shape expected when causal objects are the lower jaw’s front teeth*);

**Mark-positioning on curve** (States: *Almost regular; irregular*);

**Length** (States: *9.5mm; similar to length expected when causal objects are upper jaw’s anterior teeth; similar to that expected when causal objects are a human being’s lower jaw anterior teeth; similar to that expected when causal objects are a human being’s lower jaw’s right and left middle front teeth*);

**Breadth** (States: *Similar to breadth expected when causal objects are upper jaw’s anterior teeth*);

**Cutting edge sizes** (States: *Not completely similar to cutting edge sizes expected when the causal objects are the upper jaw’s anterior teeth*);

**Characteristics** (not specified) (States: *Somewhat similar to characteristics expected when the causal objects are the upper jaw’s anterior teeth; similar to characteristics expected when the causal object is either one upper jaw single large middle front tooth or two upper jaw adjacent anterior teeth; similar to those expected when causal objects are a human being’s lower jaw anterior teeth; similar to those expected when causal objects are a human being’s lower jaw’s right and left middle front teeth anterior teeth*);

**Injury base consistency** (States: *Different from the injury base consistency of marks 5 and 6; more similar to the consistency expected when causal object is tissue fluids (caused by vital reaction to injury) than to the consistency expected when the causal object is teeth*);

- **Characteristics observed of units being individual marks of skinmark:**

**Size** (States: *Small; moderately pointed; similar to that expected when the causal object is a pointed tooth*);

**Shape** (States: *Circular; lightly prolonged oval; oval; somewhat circular; moderately pointed; similar to that expected when the causal object is a pointed tooth*);

**Breadth** (States: *Narrow*);

**Indentation1** (States: *Present, Possibly present, Not present*);

**Indentation2** (States: *Similar to indentation expected when the causal object is a human tooth's cutting edge; Similar to indentation expected when the causal object is the lower jaw's right side front tooth*); MD/W (1999:16-20)

These characteristics and their states are then the elements of MD/W (1999)'s bitemark-index2 and are the foundation for the bitemark's profile on this index.

MD/W (1999) do not report all the units' states on all the characteristics observed: Some but not all marks are observed with respect to *furrowing* — both *present* and *not present* are used if observed. How should one interpret this? It is difficult to say whether this is a conscious choice. Maybe they believed that only the positive observations should be reported or maybe they believed that only the positively relevant markers given the truth of the claim of *BM1* should be reported. Or maybe they did not consciously choose any of these strategies, but just happened to do so — proceeding by the same kind of reasoning as Stroem (1958). I will study this further in section three of this chapter.

Nobody challenged MD/W (1999)'s decisions about the conditions denoted by *BM4* and its sub-conditions: All agreed that the skinmark was a human bitemark and that the marks nr. 1, 2, and 3 were from the upper jaw and that the marks number 4, 5, and 6, were from the lower jaw. But conflict arose on the number of individual marks observed and on which *kind* of tooth (middle or side incisor or canine tooth) was the cause of given individual marks.

MD/W (1999) state to be confident, through all their reports, that all the sub-marks nr. 4, 4a, 5, and 6 existed and that these were most likely caused by the lower jaw's right canine, the lower jaw's right side incisor, the lower jaw's right middle incisor, and the lower jaw's left middle incisor, respectively. They state to be less confident about the kinds of teeth being the causes of the marks 1, 2 and 3, and they suggest two possible alternatives: Either these marks had been caused by the upper right middle incisor, the upper

right side incisor and the upper right canine, respectively; or they had been caused by the upper left central incisor, the upper right central incisor, and the upper right canine tooth, respectively. They recommend that the former alternative was the more likely alternative (MD/W 1999:6). Their argument for this will be explicated below as they used the suspect's biting-mechanism to justify their choice.

I will just remind that the latter alternative was recommended by Stroem (1958:5). Waerhaug (1958) (the second expert in 1958) chose the alternative of MD/W (1999), but during the trial Waerhaug changed to the alternative recommended in Stroem (1958). The court-appointed expert between 1973 and 1976 also recommended Stroem's alternative (Bang 1974:5).

Thus, all the *court-appointed* experts on the case from 1973 to 2006 agreed among themselves about the kinds of teeth which was the most likely causes of the sub-marks 4, 4a, 5, and 6, but disagreed among themselves about the most likely causes of the sub-marks of 1, 2, and 3.

I have not been to able document the alternatives and the distribution of these among the expert-witnesses concerning the sub-marks 1, 2, and 3 (all the expert-witnesses denied that the suspect's teeth could have made these marks). All these denied the existence of mark 4a: This possible mark had not been observed by Stroem who had a much better sample but poorer instruments of observation. The absence of this mark, the expert-witnesses argued, indicated a biter without a lower right side incisor — which would exclude Torgersen who had this incisor present. Even if admitting the existence of a very weak such a mark it would not include Torgersen because his lower right side incisor was not damaged or smaller than its two adjacent teeth. We will come back to this when discussing the experts' arguing about *BM1.11* below.

Finally, it should be mentioned that none of the court-appointed experts or the experts-witnesses argued the presence of a mark 7 suggested (hesitatingly) by Stroem (1958).

### **3. "Is the suspect's biting-mechanism's state on the bitemark-index1 *bmi1*?" (*BM1.11*)**

MD/W (1999) found that the bitemark was "very likely" caused by Torgersen's biting-mechanism. Then they also presumed that the set of characteristics observed of this biting-mechanism was sufficiently relevant for the comparison to the set of characteristics used for the classification of the

<b>Tooth 23:</b> Upper jaw's left canine	<b>Tooth 33:</b> Lower jaw's left canine
<b>Tooth 22:</b> Upper jaw's left side front tooth	<b>Tooth 32:</b> Lower jaw's left side front tooth
<b>Tooth 21:</b> Upper jaw's left middle front tooth	<b>Tooth 31:</b> Lower jaw's left middle front tooth
<b>Tooth 11:</b> Upper jaw's right side front tooth	<b>Tooth 41:</b> Lower jaw's right middle front tooth
<b>Tooth 12:</b> Upper jaw's right middle front tooth	<b>Tooth 42:</b> Lower jaw's right side front tooth
<b>Tooth 13:</b> Upper jaw's right canine	<b>Tooth 43:</b> Lower jaw's right canine

Table 7.1: The relevant teeth represented by the notation of the FDI's World Dental Federation System

bitemark. Which characteristics were observed and how were they justified as relevant for the decision about *BM1.1* and *BM1*?

Before proceeding I will introduce a more efficient notation for referring to the different teeth than that used by MD/W (1999). I have chosen the FDI World Dental Federation's Two-Digit Notation System. In table 7.1 the right refers to the patient's right:<sup>3</sup>

MD/W (1999) state to concentrate on the anterior and canine teeth of the upper and lower jaw and observed the following characteristics of the suspect's biting-mechanism:

#### Characteristics observed of groups of teeth

**Curve** (States: *Weak, relatively broad*);

**Teeth positioning on curve** (States: *Slightly irregular, relatively regular*).

#### Characteristics observed of individual teeth

**Shape** (States: *Pointed, normal, approximately normal*);

**Size** (States: *Normal, approximately normal*);

**Position on teeth-arch** (States: *Normal, approximately normal, slightly outside/labial*);

**Continuity mesial adjacent** (States: *Small space*);

**Maximum coronal-apical height position** (States: *Labial, distal-labial, mesial-labial*);

**Maximum coronal-apical height proportion** (States: *2/3 of tooth*);

**Minimum coronal-apical height position** (States: *Mesial-palatal, distal-palatal*);

**Maximum coronal-apical height relative** (States: *Greater than both adjacent teeth*);

**Coronal-apical height relative** (States: *Less than mesial adjacent and equal to distal adjacent, more than mesial adjacent*);

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<sup>3</sup>Also known as the ISO-3950 notation: <http://www.fdiworldental.org/content/two-digit-notation>.

**Cutting edge breadth** (States: Narrowing distally);  
**Cutting edge wear** (States: Very slightly, some, moderate, significant, explicit and strong);  
**Cutting edge wear position** (States: Lingual, mesial-palatal, palatal);  
**Cutting edge wear distribution** (States: Irregular);  
**Cutting edge surface** (States: Flat, even, generally smooth);  
**Cutting edge indent** (States: Yes);  
**Cutting edge mesial corner shape** (States: Rounded);  
**Cutting edge furrow presence** (States: Yes, explicit, very weak);  
**Cutting edge furrow length** (States: As long as cutting edge, almost as long as the cutting edge, less than cutting edge);  
**Cutting edge furrow position** (States: Labial, centre, distal);  
**Cutting edge furrow shape** (States: Flat);  
**Cutting edge continuity mesial adjacent** (States: Small space);  
**Cutting edge continuity distal adjacent** (States: Explicit space);  
**Cutting edge rim presence** (States: Yes);  
**Cutting edge rim explicitness** (States: Yes);  
**Cutting edge rim breadth** (States: Narrow);  
**Cutting edge rim position** (States: Lingual);  
**Cutting edge damage** (States: Yes, slight);  
**Cutting edge damage position** (States: Mesial-labial, labial).

#### 4. "Is the bitemark-indexes relevant to the claim of BM1.1?"

I will treat this question here although it is a part of sub-condition denoted *BM3.2* in figure 7.1.

MD/W (1999), like the first expert Stroem, do not explicate any standard or best set of characteristics given the *kind* of bitemark in the Torgersen-case. The considerable experience of these two bitemark-experts makes it difficult to believe that they did not have any such reference. A few remarks indicate their opinion about the discriminatory power of some of their chosen characteristics:

The bite in [the victim]'s breast shows marks from three front teeth of the upper jaw and at least three front teeth of the lower jaw. These teeth [marks] show explicit characteristic features with respect to shape, size, and position. In particular there exist non-normal characteristics in terms of teeth's wear.  
(MD/W 1999:15)

And MD/W (1999) comment indirectly on the *reliability* of the observations by commenting on the conditions under which they were observed. They recognized that

- (a) body and limbs-position during biting being different from position during forensic examination could affect the reliability of the observations:

We examined the photographs of the deceased on the crime scene and on the examination table. These show that the left arm and the breast were in the approximate same position on the two pictures and the probability that any positional distortion of any significance is therefore low. (MD/W 1999:5)

They did not comment on the possible difference between position at first examination and position during the biting.

- (b) the method and material of photography could affect the reliability of the observations:

Figure 2a bitemark shows detail better than figure 2b bitemark (MD/W 1999:6)

An interpretation of these irregularities is complicated because the marks one can observe in figure 2a [secondary skinmark] includes a mixture which is caused by colouring caused by subcutaneous bruising and the vital reaction and by indentations caused by cutting edges [of the causal objects]. (MD/W 1999:7);

- (c) the method and material of light for visual observation or for photographic representation could affect the reliability of the observations:

The interpretation of the pictures in figures 3a and 3b is complicated because the light used is angled in order to underscore the 3-dimensional characteristics of the pictures. Considerable care is required when the characteristic features are to be assessed. (MD/W 1999:7);

- (d) and that the method and material of imprinting and modeling as well as the method and material of repeated imprinting and modeling could affect the reliability of the observations:

Many of the details visible in these figures [pictures of model] were visible on the model we examined, but the latter's details were less explicit due to material wear and the probability that this model was not the first model made of the skinmark.<sup>4</sup>(MDW 1999:7)

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<sup>4</sup>Stroem, in 1957 and 1958, may have made "second generation" models: Models from imprints from models from imprints of the skinmark. An expert involved in 1973-76 as well as a prison-dentist also made models of models. I have not been able to trace the exact number of models existing and their origin (made by whom, when, and from which imprint). This need not imply that the legal agents could not trace them

MD/W (1999) did not explicate how they were confident about the sufficient certainty of condition *BM4* and its sub-conditions.

As for the skinmark, MD/W (1999) do not report all the units' state on all the characteristics observed, do not justify this selective approach, and do not justify that the set of characteristics observed are sufficiently discriminatory for the diagnostic purpose. They merely claim that:

The suspect's set of teeth has a series of characteristics. (MD/W 1999: 9)

And, like Stroem (1958), MD/W (1999) do not discuss the relationship between their bitemark-index1 and bitemark-index2: Beyond the mechanisms introduced by the methods for creating secondary forensic items, none of the mechanisms operant during the biting are discussed. Maybe they saw such issues as irrelevant as they were prohibited from assessing them anyway, given the forensic material available to them, but they do not discuss their possible relevance either (it came to be mentioned in the later reports, but just as a matter of course).

The only legal agent requesting further justification for the discriminatory power of the markers observed by any of the experts involved was the Norwegian Board of Forensic Medicine (Board) — and they only asked for justification for one of the markers — the one used to classify Torgersen's biting-mechanism with respect to wear. In the Board's assessment of MD/W (1999) it states that:

The Board would, however, have found it purposeful that the experts had expressed their opinion about/scientific basis for how this characteristic [wear] is for the one who have bitten, i.e. the degree of dental wear required to make such marks, and the proportion of the population ('non-biters') having this degree of wear. [the Board's stressing/parenthesing] (Board 1999:2)

The Board did not ask about the other characteristics observed and MD/W(1999) do not appeal to any published studies or organizational guidelines to support their choice of characteristics and their classifications of the forensic items on these.

##### **5. "Is the suspect's biting-mechanism compatible with the bitemark?" (BM1.1)**

In the order of MD/W (1999), their next assessment concerns whether a bitemark like the one in this case could have been made by a biting-mechanism

like that of the suspect. We know that their conclusions were accepted by the legal agents involved:

- 4 [The suspect] has natural teeth with explicitly characteristic features and his system of teeth can explain all the characteristics which one finds in the bitemark on [victim]'s breast.
- 5 In our opinion it is not possible to exclude [the suspect] as the biter.
- 6 In our opinion it is very likely that the bitemark in [the victim]'s breast was made by [the suspect's] teeth. (MD/W 1999:15)

How did they justify this level of confidence about the certainty of condition *BM1.1*?

MD/W (1999) were confident that the suspect's teeth 43, 41, and 31 could be seen to be the causal sources of the skinmark's sub-marks 4, 5, and 6 respectively: "The characteristics of the bitemark and the teeth described show close correspondence" (MD/W 1999:11):

1. The bitemark's 4, 5, and 6 and the suspect's 43, 41, and 31 have corresponding *shape* being *flat arch*;
2. the skinmarks 5 and 6 and the suspect's 41 and 31 have corresponding
  - a. *cutting edge furrow-angle* being *approximately flat*;
  - b. *cutting edge furrow position* being *missing* (the suspect's 31 is reported to be in the state *centre* on this characteristic, but mark 5, mark 6, and the suspect's 41 had not been ascribed any state in MD/W (1999));
  - c. *cutting edge explicitness position relation* being *labial/lingual*; and
3. the sub-marks 4, 5, and 6 and the suspect's 43, 41, and 31, observed through transparent overlay, have clear corresponding
  - a. *shape*,
  - b. *size*,
  - c. *position*, and
  - d. *regularity*.

MD/W (1999) struggle more with the sources of the sub-marks of 1, 2, and 3 and suggest two alternative combinations: Either that these were caused by teeth 11, 12, and 13, respectively, or that they were caused by 21, 11, and 12, respectively. The latter alternative was suggested by Stroem

(1958) and Bang (1974). Waerhaug (1958) also changed to this alternative later after having first suggested the former alternative. MD/W (1999) argue that the former alternative is the more likely one:

Mark 3 was made by 13 because

- it signifies a pointed tooth.

Mark 1 and 2 was made by 11 and 12 because

- 12 is too small to be responsible for both the marks 1 and 2;
- 12 is responsible for part of the joint marks 1 and 2;
- 12's max. height and its cutting edge's shape explains mark 2 breadth broadening towards towards mark 3;
- the distance between the most distal point of the cutting edge of tooth 12 and the most mesial point of the cutting edge of tooth 13 corresponds to distance between mark 2 and 3;
- 12's cutting edge is worn, but shows no furrows, and this corresponds with the characteristic features of mark 2.
- 11 lays in an almost continuous arch with 12, particularly the labial side of the cutting edges.
- 11 cutting edge's distal level and 12 cutting edge's mesial level is different and this can explain the space observed in the bitemark.
- 11 cutting edge furrow corresponds to the furrow observed in the cutting edge.
- 11 cutting edge's uneven wear — with the more prominent side towards the lip corresponds to the same feature in the bitemark.
- a transparent overlay of the suspect's upper front teeth' cutting edge shape, size, and positioning corresponds closely to the cutting edge shape size and positioning of the bitemark (on a photo same magnification as the teeth).
- in a state of rest the suspect's biting-mechanism's lower jaw mesial line is slightly displaced to the left with respect to the mesial line of the upper jaw. In a state of motion the suspect's biting-mechanism' lower jaw has good capacity to produce a bite in which the lower jaw's mesial line appears slightly displaced to the right with respect to the mesial line of the upper jaw. This signifies that the whole lower jaw has been slightly displaced to the right with respect to the upper jaw during the biting. This capacity was corroborated by the state of the corresponding wear-facets between the upper and the lower jaw. (MD/W 1999:10-11))

MD/W (1999) argue the other alternative to be less likely,

Even if a series of possible characteristic features exists of these teeth which could correspond to the respective marks, we opine that these do not provide a good and complete explanation of the way the bite was made for several reasons.(MD/W 1999:13)

Mark 2 and 3 do not correspond to the suspects' 11 and 12 because

- the distance between mark 2 and 3 does not correspond to the distance between the suspects 11 and 12;
- mark 3's form and position do not correspond to the shape and position of the suspect's 12 — even if mark 3 appears to be oval in figure 3a and appears to be rounded in figure 2a and even if these possible shapes could have been produced by the highest part of the cutting edge of 12 "It is difficult to accept [this] as a satisfying explanation" ;
- mark 1 and 2 being on a line is at odds with the suspect's 21 being slightly displaced labially — which could be explained by the bitemark reflecting the part of 21 cutting edge's palatal side and the part of 11 cutting edge's labial side, but the 21 an 11 cutting edge wear's slanting patterns signifies that this possibility has a low probability;
- mark 2 cannot be explained by the furrowing of 11 — because the furrowing in mark 2 observed by Stroem (1958) and Bang (1974) cannot be observed of the skinmark by MD/ W (1999). If mark 2 does have a furrow it can equally well be explained by 12 and its furrowing;<sup>5</sup>
- Bang (1974)'s photogrammetric analysis is compatible with both alternative explanations of marks 1, 2, and 3.

This was thus MD/W (1999) reasoning when concluding that "[...] it is not possible to exclude [the suspect] as the biter".

### **7.2.2 BM2: The bitemark was made simultaneously with the lethal/rape injuries?**

MD/W (1999) does not address the condition of simultaneity (denoted *BM2* in figure 7.1) and could neither have done so given the time passed.

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<sup>5</sup>A possible confusion exists: MD/W(1999:13) states: "The furrow in the cutting edge of mark 2, described by Dr. Stroem and explained by being attributed to upper left middle front tooth, may just as well correspond to the furrow described in our assessment of the upper right middle front tooth. Dr. Stroem does not mention any furrow in mark 2, while Dr. Bang has noted a thin furrow. We have not been able to observe any furrow in mark 2 in the material which was at our disposal." I chose the interpretation above, but they may have meant Stroem's mark 1 when they refer here to mark 2 (which is theirs) because the marks are difficult to separate

The condition of simultaneity was not an issue during the assessments for review either.

### **7.2.3 "Were the analytical norms and heuristics agreed conducive to the purpose?" (BM3)**

In 1999, the Torgersen-case was rejected review by the Court of Appeal: the Court accepted MD/W (1999)'s recommendation that all the conditions necessary for the bitemark-proposition existed to the required degree of certainty. The defence counsel insisted that the bitemark-means as well as the other forensic means of evidence were not able to bring the case above the required threshold of probability — their argument partly resting on the "unscientific methods" applied by the court-appointed forensic experts. The decision was immediately appealed to the Appeals Committee of the Norwegian Supreme Court (Appeals Committee).

By 2000 the suspect and his solicitors had listed five issues they asked the Appeals Committee to address in a separate hearing about the bitemark-means:

1. **What is the "best evidence" for assessing the bitemark and the suspects' teeth today?** The set of photographs taken by Stroem in 1957 (of the skinmark in situ, on excised breast, on first imprint, etc.) and 1958 (the suspect's natural and modelled biting-mechanism) — which were preferred by [MD/W] — or the excised and stored breast, an imprint of the bitemark on this breast made from this stored breast in 2001 by professor Senn, and an imprint of the bitemark with unknown origin or other specification — which were preferred by the defence counsel's expert-witness, professor Senn?
2. **Which bitemark-procedure is the best approach?** The feature-based approach in which directly (or not-mediated via instruments with unknown reliability) observable markers dominate and where the less conceptualized markers observed via transparent overlay complements the former — which were preferred by [MD/W] — or the overlay approach in which markers observed via computer-generated overlays dominate — which were preferred by Senn?
3. All experts involved today (except professor Solheim) agree that the bitemark's sub-marks nr. 1, 2, 3, must stem from teeth 11, 12, and 13, but they disagree if these are the suspect's teeth 11, 12, and 13:

**Does mark 2 correspond to the suspect's 12 (as [MD/W] argue) or not (as Senn argue)?**

4. All experts involved agree that the bitemark's submarks nr. 4, 5, 6, must stem from teeth 43, 41, and 31, but they disagree if these are the suspect's teeth 43, 41, and 31:
  - (a) Does the lack of or the very weak imprint from a tooth 42 exclude the suspect as the biter given that the suspect has a tooth 42 present and 42 is not abnormal (as Senn argued) or not (as [MD/W] argued)?
  - (b) The relationship between mark 5 and 6 is "lingual"/"labial" while the relationship between the suspect's 41 and 31 is opposite — does that exclude the suspect as the biter (as Senn argued) or not (as [MD/W] argued)?
  - (c) Does mark 5 correspond to the suspect's tooth 41 (as [MD/W] argued)? Or not (as Dr. Flood argued)?
5. The relationship between the midlines in the bitemark is opposite that of the suspect's when occluded naturally — does that exclude the suspect (as Senn argued) or not (as [MD/W] argued) or not (as Dr. Flood argued)?; and
6. Is dental wear sufficiently discriminatory (as [MD/W] argued) or not (as the suspect's counsel argued)?

In section 2 above I listed the forensic items available to the bitemark-experts: MD/W (1999) opine that the preserved breast, the imprints, and the models (of both the skinmark and Torgersen's biting-mechanism) have been exposed to change and that this render these items less good evidence. They decide that the photographs taken by Stroem of the primary and the secondary items in 1957 and 1958 should be considered the best items.

Senn, on the other hand, opined differently: He claimed that the preserved breast, an imprint he made from this breast in 2001, and an imprint of unknown origin should be considered as the best items for observation. The only justification I could find for this decision was Senn's claim that the photographs are not the best means because they are not scaled (Commission 2006:98).

But the Appeals Committee was convinced by the argument of MD/W (1999, 2000) (Supreme Court Ruling 28. November 2001, cited in Commission 2006:100).

This decision made Senn's arguments against MD/W(1999, 2000) very difficult. But questions 4(a) and 4(b) were independent of the kind of secondary material used: How should one explain what was agreed among all

the experts to be an unexpectedly large space between the sub-marks of 4 and 5?

All agreed that it must have been primarily caused by characteristics of the causal biting-mechanism (any contribution by skin-characteristics is only mentioned in the passing by MD/W): Senn claimed that the suspect had tooth 42 present and not abnormal, and argued that this was reason for excluding the suspect as the biter. Senn had performed a controlled experiment in which Torgersen's tooth 42 consistently produced an indent equally explicit as the indents made by the adjacent teeth. MD/W saw it differently. A bitemark made under conditions such as in this case, they argued, is extremely difficult to recreate experimentally. Both the suspect's 43 being longer than his 42, possible variation in tissue texture, and the strength and direction of the forces applied — all these elements may explain the space. A tooth which may be expected to make a mark will thus not always make a mark in a natural context.

Much of the same kind of reasoning was used to explain the apparent disparities in questions 4(b) and 5 — that the relationship between mark 5 and 6 is lingual-labial while the relationship between the suspect's 41 and 31 is opposite; and that the relationship between the midlines in the bitemark is opposite that of the suspect's when occluded naturally: Variation in tissue texture and the strength and direction of the forces applied was again appealed to for explaining the difference in the skinmarks.

The Appeals Committee was again convinced by MD/W's explanations for these discrepancies (Supreme Court Ruling 28. November 2001, in Commission 2006:102-105).

Question 6 was also independent of the secondary forensic items: How common was the suspect's kind of wear in 1958 among the population in Oslo in the 50's? The counsel argued it to have been very common. But the Appeals Committee argued that even if such a wear was common this does not thereby provide reason to believe that many other people would have the same combination of the other joint characteristics documented of the suspect's teeth by the court appointed experts. They saw support for this decision in Board (2001) (I will return to this particular issue in the last section).

The Appeals Committee was all in all more convinced by the reports and testimonies of the court-appointed experts than those of the expert-witnesses. Some of this difference in confidence must be explained by the Board's assessments of the expert-reports.

Board (2001) found that professor Senn had appropriate training and experience in forensic bitemark-analyses, that he obviously had performed a most thorough analysis, and that his findings were generally well described and documented. But,

[...] his conclusions depend to a large degree on the confidence one can have to the opinions the expert have about which features the teeth which made the bitemark must have had. These expected features are — at least partly — presented by the expert as non-documented statements or as expert judgements. These statements and judgements — and thereby the strong conclusion that it is excluded that the suspect could have caused such a bitemark — are therefore not available for evaluation by the Board. (Board 2001:4)

Professor Senn had been supported by three other American bitemark analysts, but only professor M. Bowers provided a written analysis for the case. The Board of Forensic Medicine recognised that Bowers argued that the evidence created sufficient doubt that the suspect had made the bitemark, and that such evidence would not allow any positive identification, men could not see that Bowers had provided sufficient reasons for the claim that the suspect should be excluded.

Board (2001) found no reasons not to accredit the two other expert-witnesses, Holck (1999 and 2000) and Flood (2001): It had no objections to Flood (2001), the suspect's assisting expert on geometric analyses (via stereoscopy) of the bitemark, and found that Flood stressed his uncertainty with respect to his findings appropriately.

Professor Holck had provided two analyses, one in 1999 and one in 2000. His main argument concerned the characteristics by which court-appointed experts founded their conclusions. He argued that both the reliability of the classifications in this case and the general relevance of these characteristics with respect to bitemark-diagnoses were questionable. The characteristics observed of the suspect's teeth, Holck argued, could impossibly have the discriminatory power claimed by Stroem (1958), Bang (1974), or MD/W (1999): He appealed to the part of the literature supporting his concerns about low reliability; and stressed that Whittaker himself in 1975 had published the results of a controlled bitemark experiment (on pigskin) which showed that the ability to identify the correct biter fell from 60% at zero hours to 9% at 24 hours (Holck 1999:1-10, in Eskeland 2000; Vol III:198-207). Holck (1999) concluded by stating that there was nothing evidencing a correspondence between Torgersen biting-mechanism and the bitemark (Holck 1999:10). Holck

(2000) concerned an experiment to demonstrate the distortions of the dimensions of an ink-mark on a female left breast given various positions of the left arm, where the aim was to show reliability issues attached to bitemarks in human skin.

These two reports had been assessed in Board (2000). It generally acknowledged Holck's expert-knowledge about human anatomy and his experience with forensic assessments in physical anthropology, but:

The Board has no significant complaints to the expert's examinations. However, the Board is in doubt with respect to the degree to which the expert has a reasonably sufficient scientific competence to assess *the significance of his findings in relation to the given case*. The Board, in any way, cannot find that he has presented a sufficient basis for his relatively bombastic conclusions. This is valid for both [Holck 1999 and Holck 2000]. [The slanting is the Board's] (Board 2000:3)

The Appeals Committee thus saw the Board (2000 and 2001) as generally supporting their preference of MD/W's analyses and recommendations over those of Torgersen's experts:

As mentioned above, the Board has not found it appropriate to provide its own detailed views. After having assessed all the experts' reports and comments in this case, the Board finds it however correct to communicate its general assessment to the Court:

The "bitemark-evidence" in the Torgersen case has now been assessed by a series of specialists in forensic odontology and related disciplines and among these several experts with a solid international scientific reputation. They have collectively expressed a wide spectrum of different expert judgements in relation to the main question in this connection: What is the probability that [the suspect's] teeth could have made a bitemark such as that on [the victim] compared to the probability that the bitemark could have been made by the set of teeth of another? It is demonstrated that that the experts have different opinions of the degree to which and how particular features of a set of teeth will cause particular features in a bitemark. This leads to different opinions with respect to criteria for "match" between a bitemark and a set of teeth. There is no agreed knowledge, nor a shared opinion, concerning the weight which should be attached to "matching" features and there are no well defined criteria for "not-matching" features. If a feature of a bitemark deviates from what was expected given a set of teeth, it seems that this may be explained away by natural reasons by some experts while other experts would use it as grounds for exclusion. All in all it has been demonstrated that the contemporary "state of the art" in this sub-discipline of forensic science is such that it does not provide a basis for any strong conclusion that the given bitemark was caused by Torgersen and neither any strong conclusion that it was not.

The Board of Forensic Medicine therefore maintains and strengthens the assessment it gave to the Borgarting Appeals Court the 7. August 2000: Caution should be shown and the Court should not attach too much evidential burden to the bitemark. (Board 2001:5)

The Appeals Committee of the Supreme Court finally recognized this and downgraded the weight attached to the bitemark by the 1958-experts Stroem and Waerhaug. Under considerable doubt the Appeals Committee also found that also MD/W's conclusion was too strong. They concluded that the weight should be reduced from that given in 1958, but:

The Appeals Committee finds that the bitemark-evidence still pulls in the direction that Torgersen is the biter, but that this is not essentially more likely than that he has not caused the bitemark. (Supreme Court Ruling 28. November 2001, in Commission 2006:108).

**Concluding about the justifications for BM3.2 and BM3.3** It is difficult from the available sources to see how the crime investigators in 2001 justified that MD/W's analyses were better than those of the expert-witnesses: They obviously *trusted* the former more than the latter, but what this trust consisted in remained unarticulated: Neither the investigators nor the legal agents explicitly expressed their own expectations or standards of expert-analyses, did not perform any literature-review to form an opinion about the state of knowledge of forensic bitemark-analysis or the state of guidelines in bitemark-analysis.

The expert-witnesses did not offer anything different than the court-appointed experts: Indeed they offered alternative characteristics, alternative observational heuristics, and an alternative set of forensic items, but could merely claim that the discriminatory powers of these were better than those of the court-appointed experts. The expert-witnesses' analyses were thus no more "scientific" than those provided by the court-appointed experts.

### **1. Were the norms of inference agreed conducive to the purpose? (BM3.1)**

The last issue to be considered in this chapter concerns MD/W (1999, 2000, and 2001)'s decision that the claim of BM3.1 was sufficiently certain.

Very little information is offered by MD/W concerning their preferred standard of inference — they comment only indirectly, when they explain why they do not use statistical techniques:

The interpretation of bitemarks and possible suspect teeth is known as a very difficult sub-discipline within forensic odontology which requires significant amount of experience and knowledge. Assessments of the probability that a given system of teeth has been the cause of an individual bitemark are subjective. It is not possible to determine the probability scientifically in the same way as for other means of identification. (MD/W 1999: 4)

In an appendix MD/W (1999) comment (as mandated) on the methodological remarks made about Stroem (1958) by the expert-witnesses from 1973-1976 — Dr. Neumann and Hagen:

A forensic expert's opinion about the probability that a particular given mouth has caused a given bitemark attends to finding an explanation to all those characteristics which one finds in the bitemark and which are found in the suspect's row of teeth. The final interpretation does not say that only the mouth of the suspect could have made the bitemark. It is never possible to say this. It is obvious that an expert cannot completely exclude the possibility that another mouth with the same or alternative teeth-characteristics could have made the bitemark.

[...]

We disagree with Hagen's perception about what it should mean to compare scientifically [...]. A meaningful comparison does not require that the "participating objects should be characterized independently of each other". The comparison process starts in that way, but continues with what may be described as an "interactive comparison" which moves between the objects of the comparison. This may disclose areas of compatibility or lack of such not noted previously. This is not to change the data, as suggested by Hagen. The facts stay unchanged. What is changed is the observer's ability to see and interpret the actual evidential material.

[...]

We agree with Hagen that in a scientific comparison "everything must fit". This is only possible by the kind of interactive comparison we have described.

[...]

Hagen discusses the inferences drawn from the investigation of the bitemarks. This, again, underscores his lack of practical experience and understanding of bitemarks. Much of his discussions are based on very complicated statistical arguments which we hold to be completely irrelevant to the practical treatment necessary of a case under conditions such as those of a murder-investigation. His main arguments are based on whether Stroem could have observed the kind of detail in the bitemarks which he describes. It is clear that given our own examinations of the existing material in 1998 that even after all these years many of the the details described by Stroem is still visible and we find that this is a very strong argument supporting the observations made by Stroem and Waerhaug [the second bitemark-expert in 1958] [MD/W's quotation-marks]. (MD/W 1999; Appendix 3: 5)

Board (1999) generally accredits MD/W (1999), but the latter's grade of uncertainty expressed in the conclusion, "very likely", was met with some hesitation. Board (1999) states that it would have preferred an expression of the prevalence of the kind of wear observed of the suspect's biting-mechanism in the relevant population:

The Board finds that the experts' assessments in this context must be seen to have been *lege artis*. The results are however, that the Board does not get any basis for assessing the validity of their conclusion that "In our opinion it is very likely that the marks in [the victim]'s breast were made by [the suspect]'s teeth". The Board will add that it would have been in line with the tradition within forensic odontological dental identification (from teeth and dental records) to use the expression "likely" (as in "identity likely") in a situation where several details are demonstrated, but where there are still a presumed possibility that another suspect with the necessary dental characteristics may exist. [...] One should be aware that when [the experts] base their final conclusion very likely on comparisons between the bitemark and [the suspect]'s set of teeth, then they compare with a partly different set of teeth than that of expert Stroem and Bang [in 1974] when these two compare and conclude that the bitemark with all probability stems from [the suspect]. The fact that two different sets of [the suspect]'s upper anterior teeth are found to be compatible with the upper part of the bitemark could indicate that this part of the bitemark is not very characteristic with respect to the one who made the bite. (Board 1999:3).

In 2000 MD/W delivered a supplementary report answering questions asked by the defence counsel. Four comments are relevant with respect to the methodological norms of MD/W: One question concerned the issue of diagnostic criteria:

There is no consensus about any given number of in modern forensic odontology. In principle, 12 teethmarks in one row without any abnormal characteristics may be less useful than for example 6 or 7 marks with more available information. See R-v-MUDD, Winchester Crown Court, 1998. Only three teeth were involved in this case about a bite in a breast. Mudd was found guilty. (MD/W 2000:21)

A second question concerned MD/W (1999)'s perception of degrees of certainty:

Concerning the use of the word "certainty". To us this means 100% certainty. We make it clear in our introduction that bitemark-analysis is not like DNA-analysis where precise probabilities can be determined mathematically. [...] We use the words "very likely" because we are in full awareness that we may not provide mathematical certainty in a case about a bitemark. There

is no method for applying statistics, like in a DNA-case. We have made an assessment based on a series of factors which all works together in this one bitemark. These contain wear and pattern of erosion of the teeth, the teeth-arc's form, the positions of the teeth, distance between the teeth, the size of the teeth, and a series of details in the photographs and the imprints. We have not assessed small deviations in size and position because, as we say in our introduction, the aspiration of such a precision in bitemark-analysis has no purpose.

[...]

We have acknowledged that analysis of bitemarks is difficult and requires much experience. This is why we have not said that it is 100% certain that the [suspect] is the cause of this bite, but that his set of teeth can explain the marks and that it is very likely that he has caused it. We can not exclude that he did it. In Norway, as in The Great Britain, it is for the court to decide about the question of guilt. The claim that bitemarks normally should only be used to prove innocence has often been appealed to in court since 1954. The courts in Great Britain nevertheless still accept bitemarks as evidence for the prosecution.

[...]

Finally — we have emphasized not claiming that the material of evidence is fully objective and providing statistical results. This is never the case of bitemarks. This is why ABFO (The American Board of Forensic Odontologists) recommends using words like "probably" or most likely. (MD/W 2000:26-27)

A third question concerned the issue of the prevalence of the kind of wear observed of the suspect's biting-mechanism in the relevant population:

A larger study about dental wear in a population in Great Britain was performed by Smith and Robb (1996). In the age group 15-26 years the dental wear of the anterior teeth in the lower jaw was ascribed an average reference-number of 1.25. In the age group 56-65 years the average was 2.25.

If using Smith and Robbs method of reference, the degree of loss of dental tissue in Torgersen's anterior teeth in the lower jaw would have been given the highest but one, or the most serious category (3) described by them. This degree of wear in the cutting edges of a young person is very uncommon. (MacDonald/Whittaker (2000: 15a)<sup>6</sup>

And fourthly, concerning the issue about the meaning of their grade of "very likely" they state to adhere to the guidelines offered by Manual of Forensic Odontology (Bowers (ed.), 1995 (3.edition) where the grading "very

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<sup>6</sup>This quote is from a correction to the original 2000-report. In the latter they state that Smith and Robb (1996) shows that in the age-group 15-26 years, 5.3% was classified as having dental wear of the anterior teeth in the lower jaw being "unacceptable".

likely" corresponds to a probability between 0.5 and 0.95 (MD/W 2000: 23-24).

The Board (2001) was somewhat surprised that MD/W insisted on the formulation of *very likely* when they at the same time state that grade to represent between 0.5 and 0.95 on an analogous scale. The Board appealed to the practice in forensic genetics, in paternity-cases, where *very likely* is agreed to be reserved for likelihoods above 0.95: It is agreed among the Scandinavian forensic genetics that only ratios exceeding 19 should be allowed to enable speaking with weight that a given man is the father of the child (The Board 2001:2). Board (2001) does not explicitly ask about the risk of false positives or about the nature and degree of the relationship between markers observed of the forensic items. Board (2001:5) accredits MD/W (1999, 2000), but cautions the legal decision-makers about the value of the bitemark-means with respect to the indictment(s).

As noted above the Appeals Committee of the Supreme Court noted this and downgraded the weight which had been attached to the bitemark by all the court appointed experts. However, it still saw that "the evidence still pulls in the direction that Torgersen is the biter, but that this is not essentially more likely than that he has not caused the bitemark." (Supreme Court Ruling 28. November 2001, in Commission 2006:108).

**Conclusion about the claim of BM3.4** The Board (2001) seems not to entirely agree that the strategy of inference used by MD/W was the best possible. The Board wanted information of a kind it knew was possible for the investigative conditions: It wanted an estimate about the discriminatory potential of the expert-knowledge — in order to form an opinion about not only the probability of the suspected hypothesis conditional on the bitemark-evidence, but also the probability of the alternative hypothesis conditional on the same evidence — all ultimately to form an opinion about the risk of having made the wrong conclusion and thereby harming the aims of the decision. The board did not thereby require that this estimate should be based on a certain kind of data analyzed by a certain kind of statistical technique. It would, I believe, have accepted an estimate derived from the inter-subjective experience of bitemark-experts — even subjective experience would have been accepted. The Board wanted MD/W's *reference-groups* for the different decisions. But MD/W could not respond adequately to this request as they confused norms of inference with methods/techniques of

inference.

Just like Stroem (1958), MD/W (1999, 2000, 2001) seem to be guided by the norm practiced in everyday decisions which I in the previous chapter called "incomplete or open induction". This norm does not induce explicit deliberation on the relevant reference population and has no standardized means for assessing the risk of making the wrong decision.

How, then, did MD/W (1999, 2000, 2001)'s norms of inference compare with that of the other bitemark-experts on the case? The latter most likely adhered to the same norms: None of the expert-witnesses challenged these norms. The defence counsel had partly based their arguments in the claim that the court-experts' analyses were "unscientific", but did not proceed to specify what a "scientific" analysis would include. Nor was their own experts of any help here as their analyses were just as "unscientific" as the court-appointed experts.

The question of how MD/W (1999, 2000, 2001)'s analytical norms and heuristics compare to those used for producing more general knowledge about phenomena and mechanisms relevant to forensic bitemark-analysis will be studied in the next chapter. Here it suffices to say that MD/W's norms and heuristics were representative of those of the larger pool of bitemark-experts:

### 7.3 Was the 2001-decision about *BM* evidence-based?

Again the investigators decided that the bitemark-proposition was positively relevant to the indictment-proposition. And again we must assume that both the crime investigators and the experts knew about and intended to contribute to the aims of the investigation and the ultimate aims of the legal processing of the case — that they had no intention to undermine these. And we must presume that they did find the risk of having recommended a wrong conclusion as sufficiently small. But again there is only one weak sign of the need to assess this risk in the sources referred to in this chapter — in Board (1999, 2000), when it asked for the reference-population for the suspect's state on the characteristic of wear.

The most critical information still not provided in the written sources accumulated in 2006 is that about the reference-groups and -terms used by the experts as well as the investigators. No information was provided on (a)

the general discriminatory power of the markers observed; (b) the negation of *BM1* (that "another biting-mechanism than the suspect's is the true causal object of the bitemark"); or (c) the negation of *BM* (that "another than the suspect made the bitemark during the time specified or the suspect or another made the bitemark at a time different from the time specified). Not explicating the reference-groups and -terms is not only contrary to the basic and well known norms of scientific inference, but also contrary to the inference-norm recommended by the main organization of forensic odontology, the American Board of Forensic Odontology. And it makes the investigative decision that the bitemark-proposition (*BM*) is basically (causal- logically) positively relevant to the indictment-proposition (*PC*) not evidence-based to the standard of Premise 1 of this dissertation.

And, again, I will underscore that not being evidence-based does not imply that the investigative decision is incorrect. It may be correct or incorrect — we do not know: As long as the reference-groups are not explicit there are no means by which to assess that question.

For the decision in 1958, I recognized that the public not necessarily needed access to the details of the reference-basis of public decisions to be able to form trust and confidence in them — an appeal to the *authority* of the decision-maker or institution was a possible means of legitimacy. Then Premise 1 of this dissertation would be less relevant. But, as argued in Chapter 1, in 1997 and 2001 an appeal to authority alone is no longer sufficient: The modern public is highly educated, is convinced about democratic ideals such as equality, citizen's participation in government, and rational decision-making, and is therefore much more critical — demanding access to the means of public decision-making. Implicit reference-bases coupled with appeals to authority alone, unconsciously or not, prohibit participation and foster doubt about the intentions of public decision-makers.

There is still possible that information about reference-groups and -terms was provided orally. But it is not easy to imagine how this could have happened without leaving more traces in the written sources. Only Board (1999, 2000, 2001) contains information indicating some interest in the reference-groups used by the experts.

The conclusion about the evidence-basis of the 1997-2001-decisions about the bitemark-means must be the same as for the 1958-decision: In light of the kinds of information provided in the written sources, the conclusion is that it is more likely than not that the crime investigative decisions (that

the bitemark-proposition is positively relevant to the indictment-proposition) between 1997 and 2001 were not evidence-based to the standard of Premise 1 of this dissertation. And we may remove the condition on the conclusion about the 1958-decision: Premise 1 is relevant for modern public decisions — the modern citizen needs access to the means of public decisions to be able to form confidence and trust in these.

In an addendum to this chapter I present the Norwegian Criminal Cases Review Commission's position on the norms and standard of reasoning with respect to forensic evidence. In the next chapter I will review the current analytical norms and general state of knowledge within the discipline of forensic bitemark-analysis. The question remains the same: Are the scientific decisions about phenomena and mechanisms relevant to forensic bitemark-analysis evidence-based according to Premise 1 of this dissertation?

## Addendum

### **The Review Commission's view on legal evidence and proof**

Neither the court-appointed experts nor the expert-witnesses called on to assist on the bitemark-means in the Torgersen-case provided the kind of information needed for person-independent evaluation of (a) the decision that the bitemark-proposition positively relevant to the indictment-proposition and (b) the decision that the risk of being wrong was sufficiently low. The only agent asking for such kind of information was the Norwegian Board of Forensic Medicine.

In this addendum I will study the arguments of the Commission (2006) when they accepted that the previous courts' analyses and decisions about the relevance of the forensic means of evidence as both appropriate and correct — thus deciding that the conditions for retrial, according to Sections 391 and 392 of the Norwegian Criminal Procedure Act, did not exist for these means in the Torgersen-case.

### **7.4 Review Commission on legal assessments of evidence**

With respect to the conditions of Sections 391 and 392 of the Norwegian Criminal Procedure Act, Review Commission (2006) holds that the standard of proof should be "reasonable overweight of probability" given the precedent High Court Rulings (2000:1285 and 2004:449) (Review Commission 2006:70-71). The fourth condition of 391, 1) "cannot be excluded" was also held to be less strict than that required for general case-procedural error and requires that there exists a certain possibility that the fault affected the decision. Section 391, 3), states two alternative conditions which can reopen a case. The Commission interpreted that "seems likely to lead to" requires that a circumstance or new evidence must minimally produce "a reasonable possibility" for acquittal, etc. It also interpreted "new" circumstance or evidence to mean that it had not been presented to the judging court, and thereby had not had the power to affect the content of that court's decision.

Review Commission (2006) further stated that, normally, new assessments of evidence cannot be viewed as new circumstance. But a new expert-

assessment could be viewed as new evidence even if it was not based on new forensic material and in any case if the assessment was based on new knowledge having common support in the discipline in question (supported the High Court Ruling in the case in 2001). Given these conditions, new expert assessment of old expert statements could constitute new evidence. The theme of assessment would be the import of the new circumstances or evidence if it had been known to the court trying and deciding the case, and as related to the other evidence and circumstances present at that time (Review Commission 2006: 89-90).

Section 392, second part, has two conditions. Review Commission (2006) stated the question to be whether the case all in all now is such that it should be reopened to insure that no injustice has been caused. It reminded that a change of the Section occurred in 1993 — where "very doubtful" had been changed to "doubtful" — and that the latter only applies to case-decisions effective from 1. January 1980. The Commission further stated that there are no limitations concerning the meaning of "special circumstances": New assessments of the validity or soundness of the evidence presented to the deciding court may constitute such "special circumstances". Both before and after Section 392 was changed in 1993 its second part is seen as a last safety measure in cases in which a decision appears "very doubtful" (Review Comission 2006: 90-91).

Review Commission (2006)'s position on legal evidence, proof, and standards of proof criminal cases is a familiar one:

It is a fundamental principle of rule of law that a suspect shall be seen as innocent until proven guilty. The burden of proof belongs to the prosecutorial authority, and it is this part which has to prove, in a sufficient manner, that the suspect is guilty as charged. When a suspect's guilt is to be adjudicated, both reasonable doubt and sensible doubt shall come in his or her favour. This implies that, in order for deciding the suspect guilty, the court must be certain and convinced that all the conditions for punishment are fulfilled. It is not sufficient that there exist an overweight of probability of guilt. The court must perform an overall assessment of the jointly existing evidential material and decide not guilty if there exists a reasonable and sensible doubt. Norwegian law is subject to the European Convention for the Protection of Human Rights and Fundamental Freedoms, and its section 6 (Right to a fair trial), part 2, refers to the presumption of innocence:

*Everyone charged with a criminal offence shall be presumed innocent until proved guilty according to law.* (Review Commission 2006: 49)

The Review Commission appealed to the principle of free admittance of

evidence, combined with strict requirements concerning the weight of evidence, and the presumption of innocence as the best means against arbitrary assessments and wrongful convictions. The Norwegian legal adjudication is based on what they called a *non-arbitrary assessment* of legal evidence:

The essence of this notion was, the Commission argued, adequately expressed in Strandbakken (2003) and Andenaes (2000) (generally accepted authorities in Norwegian jurisprudence):

Assessment of evidence may never be reduced to a mathematical computation of probabilities, but must be seen in light of it being psychological cognitive/epistemic process. Subjective prejudice and frames of reference can never be the fundament of a legal judgement. Assessment of evidence must neither be based on pure intuition nor non-reflective overall interpretations. [...] The best basis for providing a correct judgement is to build on a rational assessment having as its starting point that each case is unique. (Strandbakken 2003:244 in Review Commission 2006:49)

The judge cannot restrict himself to a non-reflective intuition. The evidence must be processed by though. The presented evidence must be related to common/ordinary statements of experience when deciding its value, and on this basis the judge must adjudicate whether a sufficient degree of probability exists for him to build on. [...] Direct evidence is, for instance, a suspect's confession, witness-statements from persons who have seen the suspect committing the act, a libeling letter produced in court. This kind of evidence is evidence which directly says something about the criminal relation. Examples of indirect evidence are witness-statements about seeing the suspect nearby the crime scene at the time of the crime, blood on the suspect's clothes, [...]. That which is the direct object of proof is circumstances which in itself are not of legal importance. It is not punishable by law to be close to a crime scene, nor have blood on ones clothes, [etc.]. But the circumstances can, individually or jointly give a basis more or less certain inferences about the guilt of the suspect.

The separation between direct and indirect evidence is not something by law, and it is, in my opinion, of little value. Direct evidence too, in reality, can only provide a basis for more or less certain inferences about the guilt of the suspect. If a witness explains it saw the suspect committing the murder, then it is impossible to use this without premising that (1) the witness saw correctly, (2) that it remembers correctly, and (3) that it represents correctly. In all three premises an error may occur. In addition one has the possibility that a witness may intentionally explain incorrectly, for instance, in order to revenge on the suspect. The technical evidence (fingerprint analyses and legal chemical and legal medical analyses of different kinds) is as a rule only indirect evidence, but these may often create a certainty which is far stronger than that had by so-called direct evidence ( Andenaes 2000 in Review Commission 2006: 49)

The Review Commission noted that, usually, there will be a variety of different kinds of evidence in any criminal case. In some cases one may have that one particular evidence alone convinces the court that the suspect is guilty, in others it will be the sum of several evidence which lead to the convincing. "When assessing the strength of the evidence, both individually and jointly, one may not simply build on statistically computed probability. This is so partly because one may lack information to perform such a precise computation and partly because statistics may only be a part of that which provides a conclusion in a given particular case." (Commission 2006: 49)

The Comission drew further support for holding this notion by referring to Slettan and ie (2001) and Supreme Court Rulings (2001 and 2005):

But absolute certainty occurs rarely or never in the real world. When the burdening decision about guilt or innocence is to be taken, it will often be a margin of doubt. A sole theoretical doubt – the doubt consisting in that anyone may always be wrong – is not sufficient for acquittal. Something in the case must create doubt: Did the prime witness lie? Is it possible that he observed incorrectly or mistaken one person for another? [...] The expression "reasonable doubt" means therefore that the doubt must be reasonable and justified [...] If it, in practice, can not be doubt about the guilt of the suspect, he may be convicted. (Slettan and Oie (2001;Vol 1: 25) in Commission 2006: 49)

By the decisions concerning claims for reopening with reference to Criminal Procedural Act, Section 391, nr. 3 and Section 392, second part, it is considerably important that when the deciding court has found that there exists no reasonable doubt about the suspect's guilt this was so on the basis of immediate proof. The kind of proof in reopened cases will in contrast be mediate — possibly supplied by investigation and oral negotiations of a limited character in relation to the negotiations in the judging court. Immediate proof — that the adjudicating court itself will hear the defendant and the witnesses — is a central carrying principle in the criminal process. By the explanations given, and the added information, change, and clarification occurring through examination in court, and by the impression communicated by the personal behaviour in the courtroom, the adjudicating court will normally have a better basis on which to assess the credibility and the validity of the explanations than that which may be had by reading documents representing the explanations.

The concerns which normally caution the court re-trying a previous court's decisions (which was based on immediate proof) will be strengthened by time. New explanations will strongly tend to be characterised by weakened and changed memory over time, or explanations may not be reproduced. Technical evidence may have had their value reduced or be lost.

It is also of importance whether the decision sought re-adjudicated is justified or not. In cases by a Court of Appeal, where the decision and its reasoning is not required explicitly and openly justified, it is normally difficult to say anything certain about how the individual evidence was actually assessed by the court. It must be premised that the appellate court based its adjudication on the joint assessment of the evidence presented. It may normally be assumed that individual evidence may have played a more prominent role than other evidence. But beyond that the court judging about reopening must exhibit restrain concerning statements about how the appellate court weighed individual evidence against each other. (Rt 2001:1521 in Commission 2006: 49)

The principle that any reasonable doubt shall be to the benefit of the accused is a carrying principle in the criminal procedure. The requirement applies to the result of the evidence as such. Legal proof rests often on an assessment of several aspects which individually may have different evidential force. It is not required that each individual aspect is proven beyond reasonable doubt if a joint evaluation of all the aspects gives no reasonable doubt about the conclusion. (Supreme Court Ruling 2005: 1353 in Commission 2006: 49)

Review Commission (2006) states to subscribe to the general views about legal proof as expressed in these sources and concluded that even if doubt may be recognized for one or several of the means of evidence in the Torgersen-case, this may not necessarily imply that the case will be reopened. It repeats that the mandate of the Commission is to assess if the conditions given in Criminal Procedural Act, Section 391, nr. 1 and 3 and Section 392, second part are fulfilled.

The Review Commission (2006) thus argues that, generally, legal proof concerns the practical and immediate weighing of a complex whole of evidence against a multitude of conditions of a varied nature and that this weighing can neither be based in arbitrary intuition nor in a mathematical computation of probabilities. This might be so when all kinds of evidence are weighed together at the end of the trial.

## **7.5 Review Commission on evidence involving expert knowledge.**

But what about means of evidence involving expert knowledge? What is the Review Commission (2006)'s position with respect to standards of expert-knowledge?

In Norway both the police during the investigative phase and the judge during any phase of the processing of a case, can use any kind of expert-knowledge — traditional forensic expertise such that offered by internal personnel (fingerprint-experts, weapon-experts, photo-experts, etc) or support-personnel (forensic pathologists, geneticists, odontologists, psychiatrists) as well as other expertise not regularly assisting investigation for legal purposes. Rules exist to ensure that objectivity and quality of the expert's work: Chapter 11 and 12 in the Norwegian Criminal Procedure Act (1981/2006) states how this appointment can be done (by whom, and who can be appointed, etc.). Recall that in the Norwegian system there are *court-appointed* experts, who are required legal formally (a) to be impartial and (b) to have their written reports accredited by the Norwegian Board of Forensic Medicine; and expert-witnesses, appointed by and answering to the needs of a party in the case, who are not legal formally required to be impartial, but are scientific normatively required to be so. The latter need not, but can upon request (as happened in the Torgersen-case), have their written report assessed by the Board of Forensic Medicine. The court-appointed experts are funded by the state, but the cost of the expert-witnesses must be paid by the parties themselves. The rules, norms and expectations regulating the use and performance of experts are basically the same as those in 1958.

Torgersen's legal counsel had specifically asked the Commission to comment on the relevance of the problems discussed in a much cited paper by Saks and Koehler published in Science 2005. This paper addresses the foundational problems of identification science:

Little more than a decade ago, forensic individualization scientists compared pairs of marks (handwriting, fingerprints, tool marks, bite-marks, hair, tire-marks, etc.) intuited whether the marks matched, and testified in court that whoever or whatever made one made the other. Courts almost never excluded the testimony. Cross examination rarely questions the foundations of the asserted expertise or the basis of the analyst's certainty.

Today, that once-complacent corner of the law and science has begun to unravel — or at least to regroup. The news carries reports of erroneous forensic identifications of hair, bullets, handwriting, footprints, bite-marks, and even venerated fingerprints. Scientists have begun to question the core assumptions of numerous forensic sciences. (Saks and Koehler 2005)

Saks and Koehler studied 86 cases in which DNA-profiling identified another offender than the one convicted. They were not surprised that wrongful convictions do occur or that witness observations in these cases were often incorrect, but they were surprised that in 63% of these cases the original foren-

sic experts concluded differently than the forensic DNA-experts and, worse, that in 27% of the cases, the forensic experts had provided false or misleading explanations. Saks and Koehler observed too that 96% of the positions held in forensic science had only at most a bachelor's degree (2-3 years), 3% had a master's degree (5 years), and only 1% had a PhD (8-9 years). They argued that this indicates that a bachelor's degree is not sufficient for an appropriate socialization into the norms and ethics of scientific investigation — it is not sufficient for an appropriate cultivation of the norms concerning methodological rigor, openness, and cautious interpretations of data. Not being firmly and continuously in contact with academic science forensic science may develop its own set of investigative norms — norms which are not necessarily conducive to the ultimate purpose of forensic science.

Commission (2006) agrees that this article and its findings are generally relevant to the Norwegian forensic scientific community, but that it does not necessarily affect the experts involved in Torgersen case: The three main technical evidence in this case involved the use of experts all having substantial academic scientific training; the error rates of this particular group was not studied in the Saks/Koehler paper; and their arguments suggests that academic scientific training actually counters errors due to underdeveloped scientific methodological norms.

Yet the Commission readily admits that Norwegian courts, as other countries' courts, have been criticized for not ensuring quality requirements concerning expert knowledge. Several serious criminal cases have been reopened due to such critique. Over the years several government-mandated investigative committees delivered reports on the use of expert knowledge within the justice sector, the most relevant here being Official Norwegian Reports (NOU) 1996:15 and 2001:12.

The use of forensic scientific experts is to provide the court and the parties the necessary knowledge about the questions connected to the forensic scientific expert's subject field. Thereby the court is provided the opportunity to perform the safest possible assessment of the issues raised by the case. The use of forensic scientific occurs thus as a part of the court's assessments of the evidence.

Several requirements must be fulfilled for the court to make appropriate use of an expert's statement. [...] (1) The Court must be reasonable ensured that the expert is fully independent, both in relation to other experts and, not the least, in relation to the parties. (2) The expert must have the expertise necessary in order to assist appropriately in the given case. (3) The number of experts must be adapted to the character of the question sought answered.

Several experts are seen appropriate when the conclusions are partly based on opinion and also if it exists doubt or disagreement within the expert-discipline. (4) A written statement signed by the expert should exist at the beginning of a trial. This written statement should have been performed according to a given mandate or as answers to questions posed by the court itself as suggested by its parties. (5) The expert's statement must in terms and content be such that the court may perceive and understand it, and a possibility for further questioning must exist. (NOU 1996:15, p125)

Court-appointed medical experts need to present their report, and any later change to it, to The Norwegian Board of Forensic Medicine:

"[The Norwegian Commission for Forensic Medicine] control is to ensure that the expert-opinion has, at any time, the best possible scientific foundation, and that like cases treated at the same time shall be assessed equally across the jurisdiction [...]. An appropriate control of an expert-statement implies in practice, the following:

- an assessment of the expert's expertise (relevant and sufficient education and experience)
- an assessment of the quantity and the quality of the experts analyses relative to generally accepted scientific standards
- an assessment of whether the premises of the conclusion seems appropriately scientifically founded
- an assessment whether there is a connection between the stated premises and the conclusion. (NOU 2001;12: 105)

And, finally, Commission (2006) cites the 2001-ruling (concerning the Torgersen-case) of the Appeals Committee of the Supreme Court:

The Appeals Committee refers to the Criminal Procedure Act of 1887 which does not state the today's rules governing the requirements of expert-statements but within the limits of the purpose of the expert-analyses it must be premised that the statements must of course be scientifically appropriate according to the requirements set for the given subject field. The Appeals Committee underscores that written expert statements in criminal cases are not — neither in 1958 nor today — supposed to fulfill requirements as if they were scientific reports. A [written] expert statement, which assumedly is to be further supplied and understood through the expert's explanation and through the examination by the parties and the court, need not contain detailed explication of the methodology, method, or assessments. A natural development has indeed occurred, today one see other criteria for the elaboration of a written expert-statement than those used in 1958, but that is another matter. (Supreme Court Ruling (Rt) 2001:1521)

The Commission (2006) stresses that only the criteria for what should be documented in writing have changed since 1958 — the criteria for the

expert-analysis have not changed. So even if the expert-reports in 1958 do not explicate the methodologies, methods, and techniques used one may not infer that the report is without value. It must be premised that both parties and the court could have examined the expert about these, if this was needed.

To sum up the Commission's views about legal proof and forensic and scientific evidence: Commission (2006) does comment on the relationship between epistemological and methodological norms and the actual and immediate ability of the court to achieve the intentions and aims of immediate particular decisions in given cases, and the actual but more long term ability of the legal institution to stay close to the legal ideals and principles as these are agreed should govern the Norwegian legal system (principles such as those expressed in the European Convention on Human Rights, particularly its Article 6.2). But Review-commission (2006) comments only on this relationship as it is conditioned by the full spectrum of aims during the trial-phase: The possibility that the assessments and decisions about positive aspect of a claims are necessary premises for the assessment and decisions about the normative aspects of that claim — the former caring for a set of few basic and mostly non-conflicting *epistemic* (causal-logical) needs and the latter caring for a set of many and much more conflicting *contextual*, *case-specific*, *social*, and *emotional* needs — was not commented: It appeals to the existence of the Board of Forensic Medicine and its functions, and seem to delegate entirely to this Board the assessments and the decision whether given experts adequately serve the needs of the court.

The Commission cites the standards regularly required by this Board, but these are too general to shed any light on whether the Board routinely requires information of the kind I have specified to be necessary for evidence-based expert-statements. The Board, as we saw in the previous chapter, did ask for such information, at least with respect to the relative likelihood of the hypothesis that Torgersen's biting-mechanism is the source of the bitemark in the case, but it did not ask for the same kind of information with respect to the other diagnosis required: The relative likelihood that the bitemark was produced simultaneously with the lethal/rape-injuries. The court took for granted that both these relative likelihoods were larger than their comparison likelihoods. Maybe they were justified in granting this, but any justification does not exist in the terms of the information provided in the written reports of the experts.

## 7.6 Conclusion

I cannot but conclude that also the last decision about the bitemark-proposition in the Torgersen-case was not evidence-based to the standard specified in this dissertation. The information about the relative likelihoods of the alternative hypotheses of the two necessary diagnostic decisions of the bitemark-means was still not available in 2006. Then the court's decision that the bitemark-means (including information about motive, etc.) was relevant to the standard required by law was not evidence-based either. The decisions may be correct and no harm may have been done. But not having access to the information about the reference-bases for the positive aspects of the bitemark-means of evidence means that we have no independent instruments by which to evaluate that claim. In the modern Norwegian society — where the values of equality under the law, citizen-participation in government, and public decision-makers duty to answer to the public are highly esteemed and where the population is well educated — the failure to provide necessary information undermines people's ability to have and maintain confidence and trust in the crime investigative services and the legal institution: Many of us still wonders whether (a) Torgersen's rights, (b) the victim's rights, and (c) the resources left available to other cases were protected; we find ourselves asking what were the "real" intentions of the legal agents in this case, whether the case-management was an accident or systemic, and will we in the next case will be offered the information we need? The absence of person-independent means of evaluation, in the form of information about the reference-groups and -terms used by the investigators and the experts, are, I hold, the main reason why the Torgersen-case cannot come to rest.

However, it is not difficult to see why the Commission had to reject the case: The Commission does not have the mandate or authority to decide about basic norms and procedures — neither those regulating the investigation of positive aspects nor those for regulating the legal normative aspects. That mandate lies only with the Parliament. Indeed, the Commission has a mandate to sanction violation of existing procedural acts: The Norwegian Criminal Procedure Act, Section 226, states for instance that <sup>7</sup>

The purpose of the investigation is to obtain the necessary information  
a) for deciding whether an indictment should be preferred,

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<sup>7</sup><http://www.ub.uio.no/ujur/ulovdata/lov-19810522-025-eng.pdf> page 75

b) to serve as preparation for the court's trial of the issue of guilt and any issue concerning the determination of a sanction, [...]

If a specific person is under suspicion, the investigation shall seek to clarify both the evidence against him and the evidence in his favour. [...] (Norwegian Criminal Procedure Act, Section 226, p.75)

But how should one interpret "necessary information" and "shall seek to clarify both the evidence against him and the evidence in his favour"? This level of specification does not discriminate between the two sets of induction norms I identified in the previous two chapters —"incomplete/open induction" and "complete/closed induction". Even if the commission-members did see this ambiguity, they could not have acted on it: That would have required a broader consensus in the legal community that the ambiguity was a problem. So far, there is no such consensus.

## Chapter 8

# The evidence-basis of forensic bitemark-analysis

The investigative decisions about the positive aspects of the bitemark-means in the Torgersen-case were found, more likely than not, not to be evidence-based according to Premise 1 in this dissertation: The investigators and the experts did not provide the means necessary for independent assessments of (a) the decision that the bitemark-proposition was positively relevant to the indictment-proposition (b) the decision that the risk of having deciding wrongly about the relevance was sufficiently low, and thereby (c) the claim that the aims and values of the criminal-case process was achieved and protected. The information which was provided was of a kind which is more probable when adhering to the inference norms of "incomplete/open induction" than when adhering to the inference norms of "complete/closed induction". In the modern Norwegian democracy, the former set of inference norms — by not inducing explicit choice and justification of reference-groups — is too weak when it comes to securing legitimacy, trust, and confidence in decisions about legal responsibility.

Was the choice of reference-norms just an effect of the particular conditions of the Norwegian Torgersen-case or was it reflecting the norms generally preferred by investigators of forensic bitemark-means of evidence? This is the main question in this chapter. A second question is: What was the state of knowledge about phenomena and mechanisms relevant for forensic bitemark-analysis in the period 1997-2006?

To assess these questions I will use the information provided in publicly available written material in the period between 1974 and 2006. The collec-

tion of papers includes the studies published in scientific journals as well as research-reports, conference-papers, organizational guidelines and newsletters, books, and information-leaflets.

In section one I explain the procedures used to detect and construct the collection of papers being the source of this chapter. This collection, each item briefly graded on relevance and evidence-basis, exist in Appendix 3. In section two I identify the inference-procedure recommended by the main authority on forensic bitemark-analysis, the American Board of Forensic Odontology (ABFO). This procedure is found compatible to the standard of evidence-basis of Premise 1 of this dissertation. In section three I study the accuracy of bitemark-diagnoses. In section four I justify the relevance of my classification of papers and proceed to attend to the papers found to be relevant to bitemark-diagnosis and evidence-based and asks for the state of knowledge currently existing about the variables involved in bitemark-production on human skin.

## 8.1 The sources of this chapter

The body of material collected for assessing the questions of this chapter was constructed by several procedures: The main procedure was the use *Metalib* provided by the Library Services of the University College of London (UCL). Items responding to the possible spelling-combinations of *bitemark?* and *teethmark?* were secured. The only other condition specified was year of publication: 1970 through 2006. The search was *not* conditioned by discipline as bitemark-analysis by nature extends into several disciplines.

This collection was further narrowed by removing items not belonging to the following classes: *Forensic analysis and diagnosis of bitemarks by human teeth on human skin*. Membership was not always clear: Some items only briefly mention bitemarks in relation to a topic not relevant to this dissertation; some were too uncritical or unspecific — being ad-hoc descriptive, brief introductions or information about bitemark-analysis, or festive praising or not so festive denouncing bitemark-analysis.

The remaining papers were then subjected to a hand search for items somehow slipping through the main search. Finally, I consulted the literature-lists identified by the main organizations representing regional or international forensic odontologists to check whether the main search was satisfactorily retrieving the items as intended.

I hold that the final collection of papers and books can be considered to be as complete as possible with respect to the question of this chapter.

The nearly 400 papers was classified according to its *main purpose* (descriptive; analytic/empirical, with incomplete/open induction; analytic/empirical, with complete/closed induction); *degree of relevance to forensic bitemark-analysis*; and *evidence-based/not evidence-based* by Premise 1 of this dissertation. The criteria used will be explained and justified in section four of this chapter — as will be the distribution of the papers on these classes. An annotated bibliography is added in Appendix 3. This Appendix also contains a list of papers published prior to 1970 (not annotated).

## **8.2 The inference-procedure recommended by the American Board of Forensic Odontology**

We take for granted that modern bitemark-experts know that when they are requested by a court or a party to analyze a bitemark, then the purpose is to minimally provide

- a.** the conditions of the suspected bitemark;
- b.** the class- and individual-level diagnoses of the causal source-object of the suspected bitemark as well as the markers observed for these diagnoses;
- c.** the likelihoods of the diagnoses of b.;
- d.** the forensic items as well as the analytical and observational heuristics used for the diagnoses of b.

Secondly, we also take for granted that (1) as forensic odontology-experts they will concentrate on producing soundly justified diagnoses of physical human biting-mechanisms, physical mechanisms of biting, and bitemarks on human skin by the help of generally known and accepted procedures of inference and observation — and avoid commenting on issues not within their realm of expertise, such as the motive of biting; (2) as odontologist having been trained within the scientific institution they are familiar with the inference- norms as well as the ethical standards of that institution and the

purpose and effect of such norms and standards; and that (3) the consequences of wrong diagnoses are real and serious.

To maintain high quality diagnostic practice, forensic odontologists will be supported by regional or international organizations. There are several such organizations, but the single most relevant to the European community of bitemark-experts — in terms of being appealed to in the published literature — is the American Board of Forensic Odontologists (ABFO).<sup>1</sup> Other European and international organizations exist, but these are not regularly (if at all) cited — either because these have not specified or published any guidelines or because these are simply not recognized as authorities. In the following I will therefore concentrate on the guidelines produced by ABFO.

Which norms and procedure of inference are recommended by ABFO?

In ABFO's Diplomates Reference Manual for forensic odontology from 2008 (ABFO-manual 2008) the section "Bitemark Related Information; Scientific Methodology Review" introduces one of ABFO's objectives:

One of the [ABFO]'s objective is to improve the quality of its science. To paraphrase A. R. Feinstein, "To advance the art and science of forensic odontology, the equipment an odontologist needs most to improve is himself/herself." Since forensic scientists are presumed to be honest, we trust other scientists to be unbiased, neutral, impartial objective and always correctly using the scientific method. Many scientific claims have been found to be false or non-reproducible. The gambling phrase, "trust the dealer, but always cut the cards" should apply to every opinion promulgated by forensic scientists. Another way of stating the problem is consistent with the opinion of arms reduction: "Trust, but verify." When called upon to give an opinion, each odontologist must face three basic challenges:

- To develop a scientifically valid opinion
- To develop an opinion that is accurate
- To develop an opinion that is based on the most current, proven techniques and methodology.

Validity must be proven prior to promulgating any opinion, technique or methodology. The system by which theory progresses to fact is based on the Scientific Method. The scientific Method is a process by which a problem is investigated using properly designed experiments or collecting information from observations. (ABFO-manual 2008: 109)

What is ABFO's notion of "Scientific method"? It is worthwhile to quote the full substantiation of it as it specified in ABFO (2008):

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<sup>1</sup><http://www.abfo.org>

1. Requirements for problem solving using the scientific method
  - A. The problem to be solved must deal with the natural realm involving natural conditions and events.
  - B. The problem must be clearly defined and sufficiently limited in scope so that a hypothesis and a prediction can be developed.
2. Experimental design requirements
  - A. Problem defined
  - B. Hypothesis developed
  - C. Prediction made
  - D. Data collected
  - E. Evaluate data in light of hypothesis and prediction
3. Important definitions
  - A. **Hypothesis:** A tentative explanation to account for an observed condition or event.
    - The hypothesis must be an explanation for the defined problem.
    - The hypothesis must be testable: requires that evidence (data) can be collected to support or refute the hypothesis.
  - B. **Prediction:** an outcome or consequence that will result if the hypothesis is accurate. Probabilities can also be assigned based on the likelihood that the event will occur. Depending on the data available, statistical analysis can be performed to assign confidence intervals to the strength of the prediction.
  - C. **Variable:** generally described as anything that can potentially change (or actively be changed by the investigator) for experimental purposes. When all variables have been identified, the investigator establishes the procedures for carrying out the experiment. In biological systems, investigators must sometimes analyze data collected from observing natural phenomenon when knowledge of multiple variables is not always possible.
  - D. **Bias:** to prejudge or form opinion before all the facts are known. A definition commonly found in the medical literature is "a process at any stage of inference tending to produce results that departs systematically from true values." (Murphy, The Logic of Medicine Baltimore: John Hopkins University Press. 1976)
    - Rarely an "expert" might develop an opinion in spite of factual information. An example would be "expectational bias" or "diagnostic suspicion bias" when an investigator expects to find a certain outcome, then he/she intentionally or unintentionally finds the expected outcome.
    - Even with the best of intentions, the investigator can introduce factors that predetermine the outcome of the investigation. For example, a consultant who consciously or unconsciously has his/her opinion influenced because he/she believes that the referring agency is "always right."
    - A worst case scenario is the consultant whose opinion is affected by remuneration. These persons are frequently referred to as "hired guns". The consultant is anything but neutral, impartial or objective.
    - Another term frequently seen in the literature is "previous diagnosis bias." This type of bias could be seen when a "second opinion" consultant allows a previous diagnosis (opinion) given by the first consultant to influence the second consultant's opinion. This type of bias could occur when you know and respect another consultant's work and have that variable

influence your opinion. It can also happen the other way — if you do not respect another "expert" or have had disagreements in the past, those previous experiences could knowingly or unknowingly influence your opinion.

- Whereas self-confidence is important, consultants can be "biased" toward believing their own opinion is the only acceptable opinion, refusing to acknowledge that an opinion differing from theirs can have value. An over inflated ego can interfere with sound judgement. Without proof to support the hypothesis, the philosophy of "experience equal expertise" has no scientific validity.
- Odontologists must scrupulously avoid all forms of bias.

**E. Blinding:** the process of assessment of raw data or information without prior knowledge of potential outcomes.

**F. Validity:** the ability of the test (hypothesis) to determine or detect that which you are testing. For example, flipping a coin may give you the right answers half of the time if there are only two possible outcomes for what you are testing. For instance, we could assign a decision on a bitemark by mandating : heads = yes, the suspect's teeth left that mark; tails = no, the suspect's teeth did not leave that mark. Even though he/she will be right half of the time, an odontologist using that technique to form an opinion is incompetent and unethical.

**G. Sensitivity:** the ability of a test to detect the true positives.

**H. Specificity:** the ability of a test to detect the true negatives.

**I. Utility:** the relative risks and benefits of a test or procedure. A test that has a high probability for a false result has low utility especially if the risks are high and the benefits low. For instance, the utility of bitemark analysis is based on whether the legal system is better off with or without it.

**J. Reproducibility:** if the study is reproducible, another investigator testing the original hypothesis using the same parameters will arrive at the same (or very similar) conclusions.

**K. Reliability:** the consistency between measurements in a series of tests. Remember that the instrument are only as accurate as the investigator using them.

**L. Gold Standard:** a test that is generally accepted as the most accurate of available tests. (ABFO-manual 2008: 110-112)

The purpose of quoting the whole of ABFO-guidelines (2008)'s notion of "Scientific Method" is to show that it is compatible to the this dissertation's reference-standard — Premise 1 presented in Chapter 1: If forensic bitemark-experts approach a given diagnostic problem according to ABFO's recommendation, then the crime investigator has good reason to expect forensic bitemark-diagnosis to be evidence-based according the standard of Premise 1. Particularly: The expert's choice of reference-groups and -terms will be induced, thus providing the means necessary for independent assessment of the bitemark's relevance and the diagnostic goal-achievement.

### **8.2.1 Does bitemark-experts adhere to ABFO-recommendations?**

But can the crime investigator presume that the experts actually use ABFO's recommended inference-procedure? No study exists which is directly relevant to this question. Four studies are however indirectly relevant:

**Pretty (2003)**, as a part of a larger survey (n = 72, mostly American odontologists, volunteered after having visited the two websites hosting the survey), asked the respondents whether they adhered to the current ABFO-guidelines with respect to (a) evidence-collection from suspected biting-mechanisms and bitemark-sites: 70% always followed these, 11% follows some of them, and 17% was not aware of such ABFO-guidelines, (b) Guidelines for analysis: 73% state to follow the analysis-guidelines; 17% was not aware it existed.

**McNamee et al. (2003)** asked whether ABFO-diplomates (bitemark-experts certified by ABFO and obliged to follow their guidelines) and odontologists being members of the American Association of Forensic Scientists (AAFS) adhered to the ABFO-guidelines concerning victim evidence collection (respondents being a group of bitemark-experts attending an annual meeting of AAFS). McNamee et al. (2003) found that a majority of the respondents adhered to most of these guidelines during actual casework, except for the procedures of photography: Only 3 out of 8 ABFO-diplomats would always themselves perform the photo-documentation, 4 would sometimes let the police or the medical examiner perform it, and 1 would never perform the procedure him/her self; among the non-diplomats (26) 13 would always perform the procedure him/herself, 11 would sometimes do it, and 2 would never do it. The film-type utilized was still an individual choice at the time of the survey. This is worrisome, McNamee et al. (2003) hold, since the photo-evidence is an instrumental part of the investigation and is also the part being the most frequently challenged in bitemark-cases. Another aspect of concern was the variation with respect to the techniques used for making bite site impressions and excised tissue samples. These techniques were not standardized by ABFO in 2003.

**Pretty et al. (2001)** asked the same questions as McNamee et al 2003 (of the group of bitemark-experts attending another annual meeting of AAFS), but now concerning collecting evidence from suspected biting-mechanisms. They too found general compliance, but voiced concern about the number of experts not themselves performing the collection pro-

cedures. Pretty et al. (2001) has the same general representational issues as McNamee et al. (2003), and has also the same relevance-issues with respect to the question of this chapter.

**Kim and Sweet (1999)** studied the adherence of ABFO-diplomats with respect to wording of bitemark-conclusions. This study might have been more relevant to the question of this chapter than the two studies above, but it was not possible to get hold of this paper through my main procedures for retrieving papers. In addition, like Pretty et al. (2001) and McNamee et al. (2003), the study informed only about the adherence of a group of bitemark-experts attending an annual meeting of AAFS. I could have contacted AAFS for a copy of the proceedings of that years' annual meeting, but given its most likely low informational value I decided it not worthwhile.

I hesitate to generalize these finding to any larger communities of bitemark experts. The respondents were only an unknown portion of those bitemark-experts who attended a meeting or visited website: It is impossible to say how well these respondents' characteristics with respect to adherence to ABFO-guidelines for bite site evidence collection represent those of the American community of bitemark-experts in the year of the surveys, those of the European community that year, and those of any community in any year later. And the adherence to guideline-procedures for collecting bite-site evidence is something else than inference-methodology. The results of the above surveys are thus at best very indirectly and weakly relevant to the question of this chapter.

I must find another way to assess whether bitemark-experts in practical bitemark-diagnosis adhere to the inference-procedure recommended by ABFO-guidelines (2008). In the following section I will ask what is known about the accuracy of bitemark-diagnostic instruments (experts themselves and/or bitemark-markers).

### **8.3 Are bitemark-diagnoses generally reliable and thus generally beneficial to those using them?**

Before assessing this question we may study how good bitemark-experts are at differentiating between bitemarks with respect to causal biting-mechanisms.

An expert or a diagnostic test will be good at differentiating between

groups or individuals if he/she/it has a high ability to detect who has or has not a given characteristic or condition. The higher this ability is, the more certain it is that the reported diagnosis is correct — and the more useful this expert or test will be. In the ABFO-guidelines (2008), in its section on scientific methodology, *utility* was defined as "the relative risks and benefits of a test or procedure. A test with a high probability for a false result has low utility especially if the risks are high and the benefits low. For instance, the utility of bitemark analysis is based on whether the legal system is better off with or without it." ABFO-guidelines (2008: 111). We must take for granted that the bitemark-experts who are willing to testify in court believe that the benefits of his/her bitemark-knowledge are greater than the cost.

**Pretty (2003)** asked bitemark-experts for their opinion about this question of reliability. 72 odontologists (happening to visit one of the two websites hosting the survey) with the experience of at least one bitemark-case were included in the analysis: 33% were ABFO-diplomates; 3% AAFS (American Academy of Forensic Science) fellows; 33% AAFS-members; 24% ASFO (American Society for Forensic Odontologists) members; 2% other (including European experts). The following questions were asked and answered by these respondents:

- How many number of bitemark-cases completed?
  - > 20 cases: 10% (of these 72% was ABFO-diplomates)
  - 10-20 cases: 20%; 3-9 cases: 66%;  $\leq$  2 cases: 4%.
- Do you believe that the human dentition is unique to an individual?
  - Yes: 91%; Do not know: 8%; No: 1%.
- Do you believe that this uniqueness is replicated on human skin during biting process?
  - Yes: 78%; Do not know: 11%; No: 11%.

(96% of ABFO-diplomates believe both that dentition is unique and that it is replicated on skin during biting).
- Is a suitably trained individual able to positively identify individual from a bitemark on human skin?
  - Yes: 70%; It is not scientifically sound 5%;
  - Only in certain circumstances: 25%.
- Can you apply the statistical "product" rule to bitemark analysis?

Yes, justified: 22%; No, not justified: 9%; Unsure: 9%;  
Do not know what this rule is: 60%.

- Do you use transparent overlays as a technique for comparison?

Routinely: 63% (93% of these are ABFO-diplomates);  
Occasionally: 20%; Never: 18%.

- There are at least eight techniques for producing overlays. Which one do you use?

Digital (Sweet): 32%; Digital (Naru): 8%;  
Digital (other) 16%; Radiographic: 4%; Photocopying: 16%;  
Hand drawn: 9%; Other method 5%; Do not use: 10%.  
(18% would use more than one of these methods in any given case).

- Do you adhere to the ABFO-guidelines for evidence collection?

Entirely: 70%; Partially: 11%;  
Are not aware of its existence: 17%.

- Do you adhere to the ABFO-guidelines for analysis?

Yes: 73%; Are not aware of existence: 20%.

- Do you think bitemarks should only be used to exclude a suspect?

Yes, agree: 22% (6% being ABFO-diplomates);  
No, disagree: 69%; Unsure: 8%.

- Do you think a forensic odontologist with an appropriate level of training should continue to analyse and render opinions in bitemark cases?

Yes: 86%; Unsure: 14%.

Pretty (2003) conducted this survey to examine the hypothesis of "ivory tower" -bias in bitemark-analysis: Critical voices have increasingly accused bitemark-analysis to be inaccurate, analytically flawed, and lacking an appropriate consensus concerning technical heuristics, but nobody had yet examined whether these accusations were justified. The results of the survey of Pretty (2003) show that the main majority (91%) of the respondents believed in the first central dogma of bitemark-analysis — that biting-mechanisms are unique to individuals — and that a slightly smaller majority (79%) believed in the second central dogma — that this uniqueness is replicated on the skin during the process of biting. 96% of the ABFO-diplomates — those with the highest level of training and experience — believed both that dentition is unique and that it is replicated on skin during biting.

Pretty (2003) is worried about the high proportion of general and ABFO-diplomats who believe in the second dogma. Pretty and Sweet (2001)'s review of the published literature showed that the few efforts at establishing parts of that claim was scientifically flawed. This agrees with the review performed in this dissertation, but I will be bolder: Both dogmas are rather empty claims as anything may in principle be unique — and a unique cause will have a unique effect. The problem is to develop markers which can be reliably observed of actual human biting-mechanisms — markers which *also* have a known effect which may be reliably observed of the bitemark on human skin. This is a familiar problem in science and faces anyone needing accurate classification, explanation, or prediction: Different knowledge-domains have reached different levels of marker-development for different kinds of problem-situations. In the forensic sciences forensic genetics may be said to be the more advanced, with several sets of validated markers for different kinds of problems. On the opposite end of the continuum you find bitemark-analysis: Very few if any markers of biting-mechanisms have been validated as empirically relevant by empirical studies and little consensus exist on how to observe the few markers anticipated relevant. And worse, there is no consensus about how to observe the effects of these markers, as they are expressed on human skin *after* having been conditioned by mechanisms activated during the biting-process.

Those experts willing to testify in court and those responding to the questions of Pretty et al. (2003) thus seem to believe that bitemark-diagnosis is more beneficial than harmful to the aims of the legal processing of the case. What is the evidence of this?

### **8.3.1 Independent signs of experts' ability to include or exclude given biting-mechanisms as likely cause of given bitemark on human skin**

The point of buying and using, say, a pregnancy test is to determine whether you are pregnant or not. Some women want a child now; other women do not want a child now. Both need to be certain about the test-result and do not have the time to understand how, by which substance, the test categorizes urine-samples in "pregnant" and "not-pregnant". Both groups need to be certain, but need so in different ways: The woman wanting a child now wants a positive result to be a *true* positive, but a woman not wanting a child now

would want the negative result to be *true negative*. A given pregnancy test with probability of a true positive of, say, 69% and a true negative of, say 81% will not be bought by modern women: A risk of a false positive of 19% and a false negative of 31% is simply not certain enough for the needs. This is of course well known by the producers of the test: Reliability is simply a basic marketing criterion (this is the extreme version of the economic/budgetary reason for being evidence-based).

Pregnancy- and other diagnostic tests are just tangible instant expert-knowledge: Experts and their knowledge by accumulated experience, observation, and inference-procedure — can be considered beneficial to the degree it helps us solve or decide about certain other problems; *Any* body of information, in the form of technical tests, expert knowledge, or lay knowledge, is beneficial to the degree it is able to sort cases into the correct category.

The inclusion of true positive/negative-rates on the packaging of publicly available medical diagnostic tests is just the medical or commercial way of communicating the associated risks of contributing to Type I-error (rejecting the null-hypothesis when it is true) and Type II-error (not rejecting the null-hypothesis when it is false) in the scientific context. In the legal context one would phrase these risks as the risk of convicting a true innocent and the risk of acquitting a true guilty. The crime investigative expression would then be the risk of *contributing* to these two risks.

A common way to assess the rates of true positives and true negatives, jointly the *accuracy* of a body of knowledge, is by a technique called Receiver Operating Characteristics-analysis, or ROC-analysis. A body of knowledge is *sensitive* towards observable symptoms or traces signalling that a given case has a condition in question, and it is *specific* towards observable symptoms signalling that a given case *does not* have that condition. The sensitivity (the ability to detect the true positives) and the specificity (the ability to detect the true negatives) can be high or low: An expert, lay-person, or diagnostic test may embody knowledge making us 99.999% sensitive — able to detect close to *all* the positive cases in a group of both positives and negatives; or the knowledge is only such that it makes him/her/it 50% sensitive — able to detect only half of the positive cases. The same applies to knowledge for detecting negative cases.

An expert/test/lay-witness with knowledge enabling only 50% detection of positives and negatives is not very helpful. Then you may just as well flip a coin. My pregnancy-test above had a sensitivity of 69% and a specificity of 81% which were considered too low for the needs of the two groups of women.

In ROC-analysis one would always measure both sensitivity and specificity. Both are necessary for a complete assessment of the abilities of a given body of knowledge. But under certain conditions a joint measure such as AUC (area under the curve) may be used to express the overall ability of the body of knowledge to classify correctly.

ROC-analysis is particularly useful when a decision-maker suspects that a body of knowledge is relevant for a given decision and its purpose, but does not have the time or competence to assess that body of knowledge. It is also useful when the expert or lay-witness is not able to communicate *how*, by which characteristics, he/she sorts cases. Which level of accuracy should be required? Neither 100% nor 50% accuracy can be useful standards in practical diagnostic situations. Is 60% good enough? Above I claimed that a modern pregnancy-test needs to be more than 80% accurate if women would bother to buy/use it. Generally, the more serious the condition tested for, the higher the accuracy needed — because of the consequences of being wrong. But what if the underlying mechanism of a serious condition is inherently complex and the existing accuracy is only 70%? This is better than 50%? Again, whether this is sufficient will depend on the purpose of the decision. Swets (1998), for instance, suggested that a diagnostic test with a ROC-AUC of 0.9 should be classified as "highly accurate"; one with ROC-AUC of 0.7-0.9 as "useful for some purposes"; and one with ROC-AUC of 0.5-0.7 as "poor".

The bitemark-experts willing to testify in court believe that their knowledge is accurate to a level being useful for the purpose of the legal processing: They thus claim that their knowledge enables them to detect (a) more than 50% of the true causal biting-mechanisms of given bitemarks and (b) more than 50% of the true non-causal biting-mechanisms of given bitemark — they claim to be more than 50% accurate. That is an absolute minimum. In light of the consequences of their decisions it would not be unreasonable to require an accuracy of at least 0.7. What is the independent evidence that bitemark-diagnoses are more than 50% accurate?

**Whittaker et al. (1998)** is the first and only study of the accuracy (in terms of ROC-analysis) of bitemark-experts diagnosing real bitemarks. The diagnosis concerned whether a bitemark was made by an adult (non-accidental) or a child's (accidental) biting-mechanism. 109 respondents from England and Wales, with varying degrees of training and experience were asked to classify 50 colour photographs of natural bitemarks (varying severity and nature) according to each having been caused by an adult or child. The "gold standard" was the verdict in the case. This standard was not informed

Observer group	Area beneath ROC curve	Standard error
Senior forensic expert	0.693	0.0248
Junior forensic expert	0.680	0.0206
general dental practitioner	0.618	0.0262
Student dentist	0.690	0.0157
Police officer	0.618	0.0171
Social worker	0.634	0.0295

Table 8.1: Areas beneath the ROC curves of different groups of observers classifying bitemark's child/adult in origin

on before the classification, but previous information about all the cases could not be ruled out completely. Anonymity was ensured to the respondents. The respondents were asked to rate each of the photographed bitemarks (of different severity and nature) according to the following scale:

1. I am certain that this bitemark was made by an adult.
2. I am fairly certain that this bitemark was made by an adult.
3. It is slightly more likely that this bitemark was made by an adult than by a child.
4. I am unsure whether this bitemark was made by an adult or by a child.
5. It is slightly more likely that this bitemark was made by a child than by an adult.
6. I am fairly certain that this bitemark was made by a child.
7. I am certain that this bitemark was made by a child.

No particular characteristics/criteria were required for the diagnosis decisions. The results are presented in table 8.1

Whittaker et al. (1998) does not inform on the groups' sensitivity or specificity, but is otherwise reasonably unbiased: The senior and the junior experts had been randomly chosen from the list published by the British Association Of Forensic Odontologists (BAFO): All the senior experts had experience from real case-work, but only some of the junior experts had such experience. The general dental practitioners were randomly chosen (population unspecified) and included a wide range of experience and undergraduate training. The dental students were final year students, with one course in forensic dentistry, from Cardiff Dental School. The police officers were chosen from family support units in South Wales and were interested in or had observed bitemarks on human skin. Finally, the social workers all had experience from non-accidental injuries to children, including bitemarks. A

minor question mark may be attached to Whittaker's justification for using the court verdict as the gold standard: "It was acknowledged that the court verdict could always be questionable, although this is unlikely" Whittaker (1998:13).

The results of this study suggest that formal training in forensic dentistry is more important than experience from case-work (forensic or general dental health context) for this diagnosis, and knowledge of teeth and their arrangement *per se* is suggested to be less relevant than training for the particular purpose of forensic dentistry. Both the expert-groups were above the minimum of 0.5, but so were even the police-officers who had the poorest accuracy of all, whose accuracy was at 0.618 (S.E.: 0.0295). The increase in accuracy (to 0.693 (S.E.: 0.0248)) by having formal training in forensic odontology is not reassuring, to me at least, and suggest that the characteristics used by forensic experts are less discriminatory than the experts seem to believe according to Pretty (2003).

**Rawson et al. (1986)** studied the reliability of 7 experts in diagnosing the true biter of simulated bitemarks in the skin of a live dog (sedated) by casts of biting-mechanisms (known on given characteristics). This reliability-study was performed as a part of ABFO's effort to standardise the observations and scorings in forensic bitemark-analyses (see below) and was therefore not well described "The average reliability or accuracy in correctly matching [8] bite marks to the dentition was 66%" (Rawson et al. 1986).

**Arheart and Pretty (1999)** studied the accuracy (in terms of ROC-analysis) of 32 American ABFO-experts with the experience of at least one bitemark-case: Four sets of scaled and unscaled colour photographs of bitemarks were to be diagnosed with respect to (a) whether the case was a bitemark (seven possible certainty states); (b) whether the bitemark had any evidential value (four possible value states); (c) whether the bitemark was made or not by each of seven given models of teeth/biting-mechanisms (seven possible certainty states).

Three of the bitemarks were natural bitemarks in human skin from real cases; one was a simulated bitemark in a block of cheese from a known biting-mechanism. Three of the suspected biting-mechanisms (models) were from the person found guilty in the cases, one from the known biter, and three biting-mechanisms (models) were selected from patients in a private dental office.

Each expert was asked to perform a complete analysis of the bitemarks and write a forensic report (required according to the current ABFO guide-

Rating	Correct dentition		Incorrect dentition		Unweighted Youden's index
	n	Sensitivity	n	1-Specificity	
Reasonable medical certainty					
Probable	25	0.1953	1	0.0013	0.1940
Possible	43	0.5312	13	0.0182	0.5130
Improbable	35	0.8046	73	0.1133	0.6913
Incompatible	5	0.8437	126	0.2774	0.5663
Inconclusive	15	0.9609	536	0.9753	0.0144
Non-diagnostic	4	0.9922	13	0.9922	0.0000
Total	1	1.0000	6	1.0000	0.0000
	128		768		

Table 8.2: Sensitivity, specificity and Youden's score for each level of conclusion.

lines). The respondents were also provided the names of the submitters of the four cases and the respondents were free to gather further information if needed. The results are in table 8.2: <sup>2</sup>

The ROC-area was calculated to be 0.86 (CI: 0.82-0.91), "a fairly high accuracy, indicating that the examiners are able to correctly identify the dentition belonging to a particular bitemark." (Arheart and Pretty 1999:108). Both the other decisions — whether the case was a bitemark and whether the bitemark had any evidential value — were significantly associated with Youden-score: Partial correlation coefficient for (a) bitemark certainty and score was 0.33 and (b) forensic value and score was -0.36. Years of experience was not significantly related to score: 0.01 (p=0.958).

Aerhart and Pretty (1999) warn, however, about two aspects which conditions the ability to generalize: (1) the few bitemarks and biting-mechanisms could cause a "learning-effect"; (2) the bitemarks were all rated as having moderate to high evidential value — and does thus not say much about situations in which evidential values are lower.

It will make only limited sense to compare the accuracy indicated in Arheart and Pretty (1999) to that of Whittaker (1998) due to different kinds of diagnoses, but the former yielded a better accuracy than the study in Whittaker 1998, yet may be argued to be biased. Both studies indicated no effect of the experience of the bitemark-experts.

**Pretty and Sweet (2001)** wanted "to determine values of intra- and inter-examiner reliability, sensitivity, and specificity on both a dichotomous

<sup>2</sup>Data from combined results of all examiners. Optimal cutoff point: "possible"

scale and the recommended [ABFO] conclusion scale. [...] The impact of the examiners training and experience was measured" (Pretty and Sweet (2001:1385)).

The first part of the study concerned the intra-examiner reliability (three months apart, same cases) of 10 ABFO-experts with a high degree of training and experience. The second part of the study concerned the intra-examiner reliability of 10 ABFO-experts (different from the first study), 10 ASFO-experts all having forensic bitemark-training but only some having experience from bitemark-cases, and 10 general dental practitioners with training in forensic identification related to mass disasters.

10 simulated bitemarks in post-mortem pigskin were to be diagnosed by each of the experts: The diagnosis was based on two photographs (one colour and one black/white) of each of the bitemarks. To each bitemark was attached two biting-mechanisms in two forms — cast/model and computer-generated bitemark-overlay.<sup>3</sup>

The diagnosis concerned whether a given bite-mark was caused or not caused by any of the two biting-mechanisms attached (five levels of certainty possible). Inter-examiner reliability (70% response-rate) is shown in table 8.4:

The mean accuracy for the seven examiners' first and second attempts was 85.7% and 83.5%, respectively, with no statistically significant difference. The mean values for sensitivity (73.2%) and specificity (89.3%) for the first examination was not significantly different from those of the second examination.

Inter-examiner reliability (100% response, but two respondents removed to minimise indeterminacy):

There were no significant differences between the AUC-values of the three groups studied: This may, again, suggest that experience does not matter. The increase in the mean AUC-value from that of Whittaker (1998) may be due to this survey including both models of the biting-mechanisms and

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<sup>3</sup>An overlay is an image of the outlines of the perimeters of the anterior teeth of a given biting-mechanism: A cast is produced of the biting-mechanism, photographed according to some procedure (ABFO-specified or other), and certain characteristics — identified and ascribed value either by decision-maker or by software-algorithm independent of case and decision-maker — are the basis for the tracing of the outlines; the image is then, by hand or software, superimposed on an image of the bitemark (also created according to some procedure, ABFO-specified or other) and compared along a set of characteristics again identified either by an expert or by software.

Examiner	Kappa	S.E.	Percent Agreement
1	0.30	0.222	65
2	0.38	0.219	70
3	1.00	0.224	100
4	1.00	0.224	100
5	0.52	0.224	80
6	0.88	0.222	95
7	1.00	0.224	100
Mean	0.72		87.2%

Table 8.3: Study I summary data illustrating percentage agreement between examinations conducted three months apart.

Mean Values	ABFO (%)	ASFO (%)	GDP (%)
Area under curve	80.5 $+$ $-$ 11.8	81.0 $+$ $-$ 8.8	80.8 $+$ $-$ 8.0
Sensitivity			
Reasonable			
Medical Certainty	27.5	23.8	12.5
Probable	57.5	53.8	60.0
Possible	81.3	72.5	76.3
Exclusion	88.8	77.8	60.0
Inconclusive	100.0	100.0	100.0
Specificity			
Reasonable			
Medical Certainty	98.3	98.5	99.2
Probable	94.9	95.3	93.4
Possible	55.3	74.4	64.2
Exclusion	47.7	68.7	55.9
Inconclusive	0.0	0.0	0.0

Table 8.4: Mean values from ROC analyses

computer-generated overlays from these models: The latter will force the expert's attention to a limited set of characteristics. When also the method of defining the possible states of these characteristics is fixed, as it was in Pretty and Sweet (2001), the degree of subjectivity is further reduced. The ABFO-guidelines (2010) leaves the use of overlays optional (Pretty (2003) gave that 63% of its respondents used any kind of overlay, 93% of those being ABFO-diplomates), and if overlays are chosen, the expert may choose any technique for production and observation (Pretty (2003) gave that there are eight techniques in common use; that 40% prefer computer-based techniques, alone or in combination with other techniques; 9% prefer hand-drawn overlays only; and 18% never used such overlays).

MD/W (2000) (the experts in the Torgersen-case) claim there to be a divide among European and American bitemark-experts concerning the role of overlays in case-work: European experts prefer morphological characteristics and complement with overlays while the American experts prefer overlays over morphological characteristics.

I have not found any survey of European experts' use of bitemark analytical heuristics and no European organization is any authority in this matter, so I am unable to verify MD/W's claims. But it is difficult to assess the implication of the results of Pretty and Sweet (2001) as the selection of respondents was not specified.

**Martin-de las Heras et al. (2007)** studied the accuracy (in the terms of ROC-analysis) of two decision-makers (one bitemark-expert and one dentist without forensic training or practice) deciding whether any one of 17 biting-mechanisms (with varying presence, status, and arrangement of upper and lower anterior teeth) is "nonbiter", "probable biter", "possible biter", or "biter" of any one of 32 bitemarks (made by casts of teeth/biting-mechanisms being hinged and clamped onto non-curved, medium flexibility skin of recently dead (3-10h) piglets for 15m).

The aim was to study whether a given new 3D digital technique for producing overlays (DentalPrint software) was more accurate than an older 2D digital technique (Adobe Photoshop software).

Martin-de las Heras et al. (2007) suspected that accuracy will be enhanced by the new technique which identified the scanned cast's state on specified characteristics automatically. This is contrary to the 2D-technique, where the expert identifies these states.<sup>4</sup> A second aim was to study if

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<sup>4</sup>Intra- and inter-observer reliability of new techniques identification of states on given

Examiners	AUC	SE	CI
Expert(3D*)	0.764**	0.057	0.652 — 0.876
Nonexpert(3D*)	0.642**	0.062	0.521 — 0.763
Expert(2D <sup>†</sup> )	0.726 <sup>††</sup>	0.059	0.610 — 0.841
Nonexpert(2D <sup>†</sup> )	0.598 <sup>††</sup>	0.062	0.477 — 0.720

Table 8.5: Results from ROC analyses for both types of examiners according to the technique used to produce comparison overlays (Martin-de las Heras 2007:154 (Copyright holder John Wiley and Sons agreed use by licence nr. 3071261021)).

Cutoff	Sensitivity (%)	CI (%)	Specificity (%)	CI (%)
0-1, 2, 3	56.3	38.5 – 72.2	95.8	90.2 – 98.6
0, 1- 2, 3	53.1	34.7 – 70.5	96.9	91.7 – 99.9
0, 1, 2- 3	43.8	27.8 – 61.5	97.9	93.2 – 99.6

Table 8.6: Sensitivity and specificity values for each specific cutoff points obtained for the expert examiner using DentalPrint(c) software(Martin-de las Heras 2007:154 (Copyright holder John Wiley and Sons agreed use by licence nr. 3071261021)).

the experience of the decision-maker mattered. The results were as shown in table 8.5:<sup>5</sup>

The expert's sensitivity-values via 3D-technique were lower than the values for specificity as shown in table 8.6:<sup>6</sup>

The expert in this study were found to be significantly better than the non-expert for each of the techniques, DentalPrint and Adobe Photoshop.

Again the results are, at best, covering only experts who actually use bitemark-overlays and must be seen to be a preliminary version of a larger study as there were only two decision-makers involved.

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characteristics had been validated: ICC (3D): 0.9985 (CI: 0.9959-0.997 at 95%) and ICC (2D): 0.9999 (CI: 0.9999-1.000 at 95%) (Martin-de las Heras et al. 2005)

<sup>5</sup>\*:Comparison overlays generated from DentalPrint

\*\*: Significant differences between expert and non-expert ( $\chi^2_{exp} = 4.09; 1df, p \leq 0.05$ )

<sup>†</sup>: Comparison Overlays generated from Adobe Photoshop.

<sup>††</sup>: Significant differences between expert and non-expert ( $\chi^2_{exp} = 4.81; 1df, p \leq 0.05$ .)  
AUC, area under the curve; SE, standard error; CI, confidence intervals at 95%.

<sup>6</sup>In the table: 0=nonbiter; 1=probable biter; 2= possible biter; 3=biter; CI at 95%.

### 8.3.2 Concluding on the reliability of the bitemark-experts

The independent evidence is too incomplete to answer whether bitemark-analysis is more beneficial than harmful to legal processing. The only reasonably sound evidence existing in 2008 of the accuracy of European bitemark-experts is Whittaker (1998), which suggested an accuracy of 69.3% — when purpose is diagnosing bitemarks according to adult's or child's biting mechanism. This is better than a coin-flip, but should be compared to the poorest accuracy of the non-expert groups — 61.8%. I find it difficult to say whether the accuracy of this kind of diagnosis is suggestive of other kinds of diagnosis. The other studies had either methodological issues or attended to accuracy via specified markers which may but need not represent the markers actually used by bitemark-experts. Particularly, there are no studies about the accuracy when diagnosing the stage of the repair-process of bitemarks.

As far as I know neither European nor American bitemark-experts are subject to any accreditation schemes containing tests for accuracy. There is thus no way of knowing the false positive/negative rates of a given expert. I could find no sign in the literature that this kind of accreditation is needed, not even in ABFO-guidelines (2010). But were such accuracy-tests to be introduced they can only be one of the components when assessing the actual size of risk to aims/values in given cases — because accuracy will have to be tested under conditions only variable relevant to any actual case. The other components needed are the reliability of the markers observed in given cases and the prevalence of such markers in different populations. The knowledge about these two issues are examined in the next section.

## 8.4 What is known about the phenomena and mechanisms involved in bitemark production?

In the Torgersen-case in the previous chapter the bitemark-experts observed the following characteristics (condensed and in my "translated" terms):

- tooth-wear and mark-”wear” of a kind and degree associated with teeth/biting-mechanism's state on *occlusion*;
- tooth-position (*labiolingual*) and mark-position (*labiolingual*);

- *tooth-position (mesiodistal) and mark-position (mesiodistal);*
- *tooth-width (mesiodistal) and mark-width (mesiodistal);*
- *tooth-shape and mark-shape;*
- *teeth arch shape and marks arch shape; and*
- *teeth arch width and marks arch width; teeth arch breadth and marks arch breadth.*

The definitions of these characteristics and the observational procedures by which the experts determined the items' states on these characteristics were not explicated in the expert-reports (except stating that they had used overlays (of unspecified production-procedure)).

Upon request from the Norwegian Board of Forensic Medicine the court-appointed experts furnished information about the prevalence of one of the central characteristics observed, that of *kind and degree of wear*, by referring to Smith and Robb (1996). Assuming the suspect's biting-mechanism to represent those of this study, his *kind and degree of wear* would have been classified as uncommon — shared by 5.3% of this sample. (MD/W (2000: 15a)). The experts did not discuss the symptoms which enabled the experts to infer that the causal biting-mechanism had a particular state on *kind and degree of wear* or the diagnostic accuracy acquired via this characteristic. And they could not have appealed to any study of the relationship between the symptoms and the alleged cause as no study of it exists.

The experts did not justify the other characteristics and were not challenged to do so. Could they have done so? What is actually known about the variables involved during bitemark-production?

#### 8.4.1 The available studies and their degree of evidence-basis

Through the procedures described in section one above I retrieved 392 papers and books on bitemarks and bitemark-analysis for forensic purposes. These studies were classified according to the following terms:

**Evidence-based:** A study (1) of a specified delimited empirically testable hypothesis; by (2) ordered observable information (not necessary numerical) on specified characteristics; through (3a) an identified, specified, ethically justified/justifiable and understandable<sup>7</sup> technical procedure (enabling independent repetition of experiment) (3b) an identified or identifiable inference methodology which enable(d) an

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<sup>7</sup>Understandable to those having the same kind or level of training as the author of the experiment — who might want to repeat the experiment.

assessment of the likelihoods (not necessary numerical) of the hypothesis possibilities; and (4) including an assessment of the bias, or its effects on representational ability, involved by the specification of the hypothesis, the sampling procedure, or the technical procedure of the experiment;

**Descriptive/normative** A study which either (a) aims to be creative, constructive, informative, introductory or critical and have no intention to systematically justify or test the truth/likelihood of a delimited hypothesis, or (b) aims or claims to have tested a hypothesis but fails to satisfy the above definition of "Evidence-based";

**Case-study:** A study describing the characteristics and conditions of a particular bitemark-case or a particular instrument/material/technique used in bitemark-analysis;

**Historical or Review:** A study describing the development of a phenomenon over time; and

**Legal case:** A description of a bitemark-case legally processed in some jurisdiction.

392 studies were retrieved through the initial searching procedure and they distributed as follow on the different classes specified above:

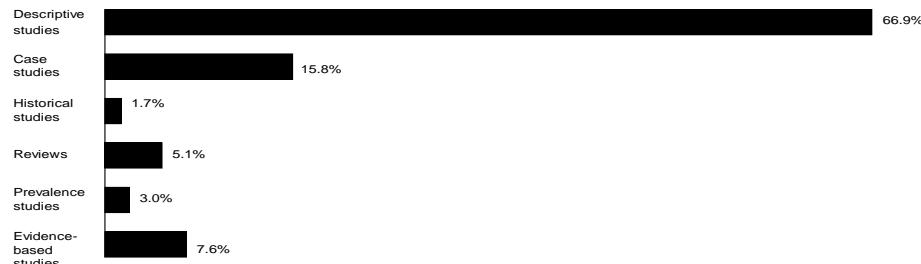


Figure 8.1: The collection of published studies on bitemark-analysis according to aim and norms of inference of the study.

33 evidence-based studies of 392, or 7.6%, may seem like a poor proportion, but this does not matter if the studies are directly relevant to the questions critical to forensic bitemark-diagnosis. In the following I will assess the relevance of the studies under each of the two main diagnostic criteria of forensic bite-mark analysis: First those concerning diagnosis of a suspected bitemark's causal object or biting-mechanism, then the diagnosis of its time of occurrence. I shall concentrate on studies directly relevant to the observation of forensic items — bitemarks and biting-mechanisms. 8 experimental studies will then be omitted due to being only indirectly relevant to my purpose: Four studies attend to techniques for correcting distortions caused during the photographing procedure; and four studies attend to distortion of bitemarks on skin excised and stored in given fixatives over given time.<sup>8</sup>.

#### 8.4.2 Evidence-based knowledge of characteristics relevant for bitemark- diagnosis.

**Rawson et al (1984)** is the first study of a commonly observed bitemark-characteristic: Kind and degree of rotation of submarks of bitemarks and of teeth in biting-mechanisms. Rawson et al. (1984) study rotation of 397 bitemarks in flat wax-plates, made through controlled biting with natural biting-mechanisms known to represent the "general population" (American) on age, race, and sex. The purpose was to "[...] establish the scientific base for the statistical analysis of the uniqueness of the human dentition" (Rawson et al. 1984:246). **Rotation** was defined as a given anterior tooth's angle between its mesio-distal centre-line and the mesio-distal line between the two central incisors relative to a coordinate system constructed by a line from the midpoint between central incisors and normal on the line between the cusps of the two arch-canines in the jaw. Rawson et al. (1984) specify the number of rotation-values possible for each tooth of the twelve anterior teeth (canine through canine in each jaw); demonstrate, via a binomial model, how one may calculate the probability of different **rotation-profiles**, and argue that this profile alone enables discrimination between biting-mechanisms to

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<sup>8</sup>Studies of techniques for rectifying distortion caused by photo-procedure: Krauss (1984); Lewin (1989); Bowers and Johansen (2001); and Awd (2006)

Studies of distortion of secondary bitemarks caused by surgical or preservation procedure: Brzozowski et al. (1999); Brzozowski et al. (2000); Low et al. (2001); and (Rotwell et al. (2001)

the individual level. This study also defines and measures **arch-widths** of biting-mechanisms and their bitemarks.

Rawson et al. (1984) recognise that the study only demonstrate the discriminatory power of **rotation-profile** with respect to bitemarks in flat wax-wafers from known biting-mechanisms, not with respect to bitemarks in human skin from unknown biting-mechanisms. The relevance of this study to practical bitemark analysis thus remains weak until studies can account for the way and strength in which **rotation** — as this concept is specified and observed in Rawson et al. (1984) — of bitemarks on flat wax co-varies with the same **rotation** of bitemarks on objects with geometric and visco-elastic properties similar to human skin. Rawson et al.'s specification and observation of **rotation** is just one of several: No consensus exists on how to specify and observe **rotation** — some include a tooth's posterior/anterior or labial-lingual relation to specified arch-curve, the reference systems for value-ascensions vary, and some prefer the name of "position" and implicitly or explicitly refers to either mesial-distal or labio-lingual or both; and ABFO-guidelines (2008) does not recommend any particular specification/observation. A minor point may be added: Rawson et al. (1984) assumed independence between the individual tooth-rotations, an assumption which was not justified in the paper. This critique is, however, not very constructive recognising that the study is the first evidence-based study on the discriminatory power of this frequently used bitemark-characteristic.

We must wait until 2006 before someone picks up the theme from Rawson et al. (1984): **Bernitz et al. (2006)** uses a similar concept of **rotation** as Rawson et al. and attends to the prevalence of this marker in a South-African population. The relevance of this study to practical bitemark-diagnosis is similar to that of Rawson et al. (1984): Bernitz et. al did not go beyond bitemarks in flat wax-plates either. By 2010 there was still no study of this kind of rotation of bitemarks on objects with geometric and visco-elastic properties similar to those of human skin, nor about the co-variance between the rotation of such bitemarks and that of natural biting-mechanisms.

Rawson et al. (1986) tried to move forward: This is a much cited study performing two experiments to study the reliability of experts using 13 characteristics defined and specified by ABFO-guidelines (1984). The purpose was to classify bitemarks on human skin made by natural biting-mechanisms (known true biters) under controlled and natural conditions: In the first experiment 21 experts classified 3 simulated bitemarks with different degree of distortion; In the second experiment 41 (ca. 50% of initial sample) experts

classified 4 natural bitemarks by known biters. The characteristics observed were as follows:

1. All teeth in mark present in the suspect's mouth (\*One point per arch if true)
2. Sizes of arches consistent (\*One point per arch if true)
3. Shape of arches consistent (\*One point per arch if true)
4. Teeth and mark in same labiolingual position (rotated or normal) (\*One point per tooth)
5. Teeth and mark in same rotational position (rotated or normal) (\*One point per tooth)
6. Vertical position of tooth re. occlusal plane matches depth of plane (One point per matching tooth)  
(use only in unusual cases)
7. Spacing between adjacent marking edges (\*One point per space)
8. Mesiodistal widths of tooth matches mark (\*One point per tooth)  
use only if individual tooth is clearly marked)
9. Labiolingual width of tooth matches mark  
OR attrition of edge matches mark (\*\*Three points per tooth)
10. Distinctive curvature of tooth incisal edge matches mark (Three points per tooth)  
(use only in unusual cases)
11. Other distinctive features (fractured teeth, unusual anatomy) (Three points per tooth)
12. Suspect has one edentulous arch and this is reflected in bitemark (Three points if true)

\* Three points if feature is significantly distinctive; \*\* Only in case permitting accurate measurement

Rawson et al. (1986) claim to have demonstrated a high degree of reliability among observers in scoring the bitemarks on all the variables except variables 7, 6, and 10. But this is at best a highly contingent statement — a contingency the reader must spend time to figure out for him/herself by carefully scrutinizing the statistics and the text. Table 8.7 shows that high reliability can at best be accredited to all the variables for bitemark-case I (simulated on live sedated dog) by casts of teeth under conditions securing minimal distortion of the characteristics to be scored. The other cases are only conditionally reliable, with variable 1 as clear, 2 and 3, less so, and the rest not reliably scored.

	Coherent scoring ("small variance")	Incoherent scoring ("larger variances")	Difficult to interpret ("many zero's")
<b>Bitemark-case I</b> (simulated, not distorted)	Variables 1, 2, 3, 4, 5, 8, and 9	Variable 7	Variable 6 and 10
<b>Bitemark-case II</b> (simulated, medium distorted)	Variable 1	Variables 2, 3, 4, 5, 7, 8 and 9	Variable 6
<b>Bitemark-case III</b> (simulated, Very distorted)	Variable 1		Variables 2, 3, 4, 5, 6, 7, 8 and 9
<b>Bitemark-case IV</b> (natural, distortion unknown)	Variables 1, 2, and 3	Variables 4, 5, and 8 ("very fluctuant")	Variables 6, 7, 9, and 10
<b>Bitemark-case V</b> (natural, distortion unknown)	Variables 1	Variables 2 and 3 ("some spread" ) 4 and 5 ("big spreads")	Variables 6, 7, 8, 9, and 10
<b>Bitemark-case VI</b> (natural distortion unknown)	Variables 1, 2, and 3	Variables 4, and 5 (big "variances")	Variables 6, 7, 8, 9, and 10
<b>Bitemark-case VII</b> (natural distortion unknown)	Variables 1, 2, and 3	Variables 4, and 5 (big "variances")	Variables 6, 7, 8, 9, and 10

Table 8.7: The results from study by Rawson et al. (1986): Degree of reliability in scoring ABFO-variables.

And further, what are these mean-scores and their standard deviations actually telling us? A score is the sum of particular scores — some of these in turn being the sum of as much as twelve such particular scores. There are thus many combinations by which to arrive at the total score on a given variable. This makes the measures for that variable not very informative. Perhaps Rawson et al. (1986) accounted for this, but it is not reported in the paper. In addition, the scoring sheet, if the respondents were given instructions similar to that presented in the paper, leaves plenty of room for confusion about appropriate procedure. The study fulfils my criteria for being experimental, but the presentation of the results makes at least me doubt (1) whether the study actually demonstrate high reliability among decision-makers as claimed and (2) whether the reliability observed indicates the decision-makers ability of having same total score only or their ability to score same on partial scores as well. I hesitate therefore to make this study signify anything about the reliability of experts in classifying bitemarks via these characteristics.

**Sweet, D., Bowers, C. M. (1998)** Studied the reliability of experts in determining **area** ( $\text{cm}^2$ ) and **rotation** of 8 individual anterior teeth of 30 biting-mechanisms (Caucasian population, not further described) via five different overlays-procedures. Clear differences were demonstrated, with the computer-based procedure as the best. But the discriminating powers of the two characteristics via the computer-method were not reported and only the authors themselves constituted the decision-makers: This study is thus only evidence for the claim that these two authors are made more reliable by one procedure than the four others when identifying *area*- and *rotation*-profiles of biting-mechanisms.

**MacNamee et al. (2005)** provides more information in their study having the same purposes as Sweet and Bowers (1998): MacNamee et al. compared the reliability of 30 experts, with different experience from practical bitemark-analysis, when identifying *area*-profiles and *position*-profiles of biting-mechanisms through two different but commonly used computer-based procedures. Their object and observation of *position* are quite similar to those of *rotation* in Sweet and Bowers (1998) and Rawson et al. (1984), i.e., mesio-distal angle to a specified base-line. The discriminating powers of the two characteristics of **area** and **position** are provided: Both procedure A and B's definitions of **area** yielded poor inter-examiner and intra-examiner reliability (reliability coefficients (given a "a suitable" model and ANOVA): Technique A (inter-examiner) 0.327 and (intra-examiner) 0.527; and tech-

nique B (inter-examiner) 0.437 and (intra-examiner) 0.550.

The coefficients for **position** were much better: A (inter-examiner) 0.946 and 0.997 and A (intra-examiner) 0.947 and 0.997; B (inter-examiner) 0.964 and 0.993 and B (intra-examiner 0.964 and 0.993).<sup>9</sup> McNamee et al. (2003) also found that the effects of experience on reliability — for both **area-** and **position-**identification — were small and insignificant.

This study is evidence justifying the expectation that bitemark-experts using either one of these computer-based procedures for identifying a biting-mechanism's profile on *rotation* will arrive at the same profile for that mechanism. Is the study also evidence justifying the expectation that experts will be equally reliable when ascribing *rotation*-profile to a bitemark in human skin? Yes — since the process simply provides relative distances between points in a defined space. Can we then infer that only biting-mechanisms found to have the same profile on *rotation* as a given bitemark can make up the base-rate for the true cause of that bitemark? No — since other characteristics will interfere during the biting-process and make the relationship between the two rotation-profiles contingent: Both biting-mechanisms with the same and those with different *rotation*-profile may produce bitemarks with this rotation-profile.

**Barsley and Lancaster (1987)** studied the distribution of *arch-width* in a sample (1198) of biting-mechanisms (casts) of dental school clinic patients (population not specified): Mean mandibular and maxillary widths were found to be 2.81cm and 3.59cm, respectively, which is slightly more than what Rawson et al. (1984) found — 2.50cm and 3.23cm respectively, but the two studies' samples had different proportions of female/male, black/white, etc. Again the results of this study can be used to justify the classification of known biting-mechanisms, but can only become relevant for practical bitemark-analysis if studies are done on the nature and degree of the correlation between the *arch-widths* of biting-mechanisms and that of bitemarks in objects with geometric and viscoelastic properties similar to those of human skin. The same applies to **Kouble and Craig (2007)** who studied the incidence of missing anterior teeth among 1010 patients (16 years +) in South Yorkshire, UK.

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<sup>9</sup>Two coordinates observed for **position**. The similar values are not my typing errors: They are the figures reported in the paper.

## 1. The lack of consensus on specification and observation of characteristics

One of the main challenges to current bitemark-analysis is the low degree of consensus among bitemark-analysts concerning the identification, specification and observation of the basic characteristics believed to be relevant to forensic bitemark-analysis: No organisation seems to have taken or been given the responsibility of coordinating individual analysts in their efforts to develop forensically relevant knowledge. ABFO is frequently appealed to but has not managed to become the authority required for adequate development. There seems to be an agreement that the characteristics identified in ABFO's scoring-scheme and studied by Rawson et al. (1986) is relevant, but there is yet no agreement about the procedures by which these characteristics should be observed.

Modern computers and software could have offered some standardizing help, but the quickly arising number of software on offer, with different degrees of person-independent ways by which characteristics are selected, coupled with a lack of validation of any of these procedures for bitemark-analytical purposes just add to the fragmentation. One might for instance be excited by the prospect of 3D imaging-software considering the geometric challenges to bitemark-analysis:

**Blackwell et al. (2007)**, for instance, studied the accuracy of 1 decision-maker identifying five morphometric characteristics using a procedure involving 3D imaging (3D Rugle3 Software-program) and an algorithm developed for quantitative comparison of bitemarks in flat wax (acrylic) and human teeth/biting-mechanisms: 42 dental students each made one bitemark into flat wax-plates (acrylic) and provided casts of their maxillary and mandibular teeth. 16 teeth (first molars, canines, incisors) in each the maxilla and the mandible were marked on 42 morphometric landmarks and transformed into five variables. Logistic regression was used to obtain a model or algorithm (cross validated) for a match, and ROC-analysis was performed to assess the accuracy: The procedure gave a true positive rate of 78% and a false positive rate of 15%.

**Kieser et al. (2007)** studied the reliability of 1 decision-maker identifying **shape** and **size** of 12 anterior (canines and incisors) teeth of 50 teeth/biting-mechanisms (postoperative unrestored orthodontic casts, assumed low level of individuality) through geometric morphometric landmark procedure. The reliability of this decision-maker in identifying the

characteristics through this process was high — the Intraclass Correlation Coefficient being 0.95 at 0.01-level. The study also yielded a low and non-significant covariation between *shape* and *size* for the sample: Upper jaw measurements were correlated  $atr = 0.38$  ( $p = 0.35$ ); lower jaw measurements at  $r = 0.52$  ( $p = 0.08$ ).

And, finally **Martin-de las Heras et al (2005)** studied the reliability of 5 experts using DentalPrint software in identifying seven characteristics of an unknown number of biting-mechanisms — demonstrating very high reliability for all the decisions: Intraobserver reliability (one observer only) was observed to have an Inter Class Correlation Coefficients (ICC) of 0.9985 (Confidence Interval, CI, at 95%: 0.9959-0.997); and interobserver reliability was observed to have an ICC of 0.9999 (CI at 95%: 0.999-1.000). Under the section on accuracy of bitemark-experts we saw that Martin-de las Heras et al (2007) demonstrated that the accuracies of one expert and one non-expert (PhD-student in forensic odontology) using DentalPrint for diagnosing simulated bitemarks on post-mortem pigskin made by casts of 17 teeth/biting-mechanisms (controlled force and direction) were 76.4% (CI for the area under the curve from the ROC-analysis: 0.625-0.876) and 64.2% (CI for AUC (ROC): 0.521-0.763) for the expert and the non-expert respectively (statistically significant difference) — which was slightly more (difference not commented with respect to statistical significance) than the AUC's observed given a software program only allowing observation of two-dimensional objects (0.726 (IC at 95%: 0.610-0.841) vs. 0.598 (IC at 95%: 0.477-0.720)).

Martin-de las Heras et al. (2005, 2007) may be considered to be the more relevant of these three studies of these computer-based procedures for observing three-dimensional objects. But whether they also justify the use of DentalPrint over the other procedure for observing two-dimensional objects is impossible to say as the difference in accuracy was small and uncommented with respect to statistical significance. Both Blackwell et al. (2007) and Kieser et al. (2007) seem to indicate that the use of computer-based heuristics for observing three-dimensional objects will enhance the objectivity of the observations of objects.

One may not forget, however, that human conceptualization, decisions, and actions intervene on several levels of this procedure as well and will make any actual or case-based application less reliable than what is demonstrated in the studies — even if the conditions of the actual case under examination are as pure as those of the experiments in the studies.

The lack of consensus on characteristics and procedures for observing

these is thus a serious challenge to bitemark-analysis: Cooperation in research toward a common goal is needed, but is difficult to bring about if there is no organisation having the coordinating responsibility.

### **Critical gaps in the knowledge about bitemark-production**

This basic lack of consensus must be one of the reasons why four other challenges exist for bitemark-analysis as well: The need for more (a) knowledge about the co-variation between characteristics observed of biting-mechanisms and the corresponding characteristics observed of objects with geometric and visco-elastic properties similar to human skin; (b) knowledge about the mechanisms operant during the process of biting and the interaction between these mechanisms and the characteristics observed of resting forensic items; (c) knowledge about the characteristics relevant for the second bitemark-criterion, that of the time of occurrence of the bitemark; and (d) knowledge about alternative diagnostic inference-procedures.

The studies reviewed above, although few, suggest that the more the conditions of the experiments approach the conditions of naturally occurring bitemarks, the lower the accuracy of the bitemark-experts becomes — both the false-positive rates as well as the false negative rates increase. In other words, the second dogma of bitemark-analysis — that the "uniqueness" of a biting-mechanism is replicated on human skin during biting process — seems still to be more of an ideal than an empirically justified truth. The practical implication is that biting-mechanisms with profiles different from that abduced from a natural bitemark can *not* be excluded from the population of possible causal biting-mechanisms.

Unfortunately, until 2008 no study being categorised as "evidence-based" had attended to this possibility: (1) No study exists which attends to the relationship between A: characteristics observed of natural biting-mechanisms and their bitemarks in flat objects without no or low viscoelastic variability and B: characteristics observed of bitemarks in human skin or objects with properties similar to those of human skin; (2) no experimental study exists which attends to mechanisms suspected to condition the relationship between A and B; and the discourse on epistemological norms, inference-procedures, and standards are almost non-existent.

This state of knowledge at the end of 2008 is possible only if bitemark-experts either are not aware of the possibility that bitemark-mechanisms with given profiles can produce bitemarks with different profiles; do not take

this possibility seriously; or do not believe this possibility to be practically relevant. And this in turn is only possible if the epistemological norms among bitemark-analysts are different from those recommended by ABFO or most western academic institutions.

The studies being the sources of this chapter do not include papers published after December 2008, but I have noticed two later studies which might indicate a change of attitude and a will to remedy the current state of bitemark-analysis: **Radford et al. (2009)** studied the difference in observation of given characteristics of bitemarks in flat objects — such as the dental wax-plates used to record characteristics of biting-mechanisms — versus objects having a form (but not viscoelasticity) similar to the human arm. Characteristics defined via landmark and semi-landmark analysis (3-D morphometric) and observed on 20 bitemarks in dental wax on (a) flat object and (b) rounded object yielded results which were consistent with the suspected hypothesis of difference but not with its alternative: The authors thus saw reason to question the use of traditional flat wax-plates to reconstruct bitemarks for forensic diagnostic purposes. **Stols and Bernitz (2010)** demonstrate a technique by which to account for the differences between biting-mechanisms and bitemarks, differences due to variables operant during the biting-process, due to change of positioning, or due to storage of tissue-specimens. I am unable to say anything about the relevance of these studies to practical bitemark-diagnosis as I have not assessed them properly.

But no matter how good their quality, these two studies can not alter the general impression that the current state of knowledge about bitemark-production in human skin is poor. Bitemark-production is certainly among the more complex processes and this is a relevant reason for the state of knowledge, but equally relevant is the lack of consensus among bitemark-analysts about bitemark-markers and the ways in which to observe these markers. Lack of consensus is in turn due to the failure to establish an organisation which can coordinate the knowledge-production and enforce a standard of inference agreed to be appropriate for this knowledge.

So far this review has only attended to the first criterion of forensic bitemark-diagnosis — the diagnosing of the bitemark's causal biting mechanism. The review of the state of knowledge for the second criterion — the diagnosis of the bitemark's time of occurrence — is the subject of the next section.

### 8.4.3 Evidence-based knowledge for diagnosing a bitemark's time of occurrence

The second criterion of bitemark-diagnosis is a necessary criterion because of the possibility of the bitemark being irrelevant to the legally relevant injury.

There is, at the end 2008, only one study which could have been directly relevant to this bitemark-criterion — Avon et al. (2006) — but it is not relevant as it does not qualify as "evidence-based" as this was specified for my classification of the existing literature (see section 3. above). **Avon et al. (2006)**' hypothesis is that, in bitemarks suspected relevant to lethal injury but in site affected by livor mortis, specified histopathological/microscopic characteristics (presence of unspecified erythrocytes in different layers and zones around skinmark) are better than clinical/macroscopic characteristics (**morphology, colour**) for diagnosing whether a bitemark was made ante-mortem or post-mortem. Experimental bitemarks were created by letting 1 chrome-cobalt teeth/biting-mechanism make 6 bitemarks in thorax and abdomen skin of each of 3 live and later sacrificed female piglets 12 weeks old (4 bitemarks ante-mortem, 2 post-mortem). The results were that unspecified erythrocytes were present in fat- and muscle-tissue of ante-mortem made bitemarks, but not present in post-mortem made bitemarks; unspecified erythrocytes were present in blood-vessels in both ante- and post-mortem made bitemarks; and unspecified erythrocytes were not present in connective tissue. Unfortunately, Avon et al. (2006) do not inform about the reliability of the technique used to determine presence/absence of erythrocytes. The study is relevant to practical bitemark-analysis in the sense that it warns that clinical characteristics of colour and morphology for diagnosing time of bitemark could be more uncertain when the bitemark is affected by livor mortis, than if it is not. Whether one then should better observe presence of erythrocytes is a question not answered by the study.

Bitemark-experts have shown an even less interest in the characteristics for diagnosing time of occurrence than in the dermatological conditions relevant for the diagnosis about causal biting-mechanism.

Is this so due to bitemark-experts seeing this sub-diagnosis to require knowledge outside odontology — that it is the responsibility of the medical examiner? This is possible.

The question of timing of skin-injuries for forensic purpose is an old one — as it is a standard diagnostic criterion for any skin-injury suspected relevant to a legal injury. The medical examiner is thus well familiar with this

diagnostic decision and the information required for it. The basic relevant physical mechanism is that of *wound-repair* or *tissue-restoration*: From the time of impact and to the time of forensic examination, the tissue in question will pass through different stages of repair or restoration. Concentrating on human skin, these stages may be determined by different characteristics observed through different technical and conceptual heuristics. There are clinical and macroscopic characteristics, such as presence of blood, colour of bruising, the texture of the wound-edge and the surrounding tissue, etc. via minimal use of technical heuristics; microscopic characteristics such as leukocyte infiltration and erythrocyte-presence may be assessed through histological techniques; and enzymatic characteristics (presence, amount) and their triggers may be assessed via histochemical, biochemical, and immunohistochemical techniques.

As for the first diagnostic criterion of bitemark-diagnosis, the diagnosis of a skin-mark's time of occurrence must select the appropriate set of characteristics on the basis of the prior classification on certain class-characteristics. It is therefore impossible to say anything general about which is the most relevant *time-markers* in a given case. Further, the choice of best markers will also depend on the resources available to the medical examiner: Some forensic examiners will have the best possible training, time, and equipment possible — enabling the use of the most advanced and reliable techniques and enabling observations of the most reliable markers; other examiners lacking training, time, or equipment, must resort to the less reliable markers, such those via clinical and macroscopical techniques. A third factor affecting the choice of best markers in a given case is the anticipated evidentiary role of a skinmark. And, finally, a fourth factor is the analytical norms and inference-procedures adhered to or required of the medical examiners, the investigators, and the legal agents.

The different techniques, markers, and the procedures for forensic determination of time or age of a skinmark are fairly well established, but the accuracy of the techniques and the markers vary: Some are evidence-based known to be generally more accurate than others, some are conditionally more accurate.

I would have preferred to review the state of knowledge and the level of agreement among forensic medical examiners in the same manner as above. But the number of studies (experimental and others) published and the level of technological and medical-specialist knowledge required for a thorough assessment of their relevance for forensic diagnosis were decided outside the

scope of this dissertation. The incomplete review I did perform suggests a much higher proportion of studies qualifying as evidence-based according to the definition in section three above — much higher than for the first bitemark-criterion. But the same problem may exist for this second criterion as well: The analytical norms adhered to when producing more general knowledge for publication in a scientific journal may differ from those adhered to when producing case-specific knowledge for presentation in a court — even within the same person.

## 8.5 Conclusion

In light of the published studies I cannot but conclude that there is a poorly developed state of knowledge about the characteristics relevant for diagnosing

- (a.) skinmarks with respect to it being a human bitemark or not;
- (b.) bitemarks with respect to it being caused by given causal teeth/biting-mechanism; and
- (c.) bitemarks with respect to it being caused simultaneously with control-injury,

and that there are one main reason for this state of knowledge, namely the low level of consensus among the bitemark-experts with respect to

the specification of anticipated relevant characteristics;

the observation of anticipated characteristics; and

the analytical norms and decision-criteria required for knowledge production — be it for general knowledge purpose or for forensic diagnostic purpose.

This low level of consensus is, in turn, due to bitemark-analysts not having been able to establish any authoritative body which is given the responsibility of identifying the most relevant research-areas, coordinate research, enforce analytical norms and standards, and provide best practice guidelines concerning choice and use of terms and technical procedures.

Mainly because of the lack of consensus there is in 2010 an almost complete absence of

- bitemark-expert initiated experimental studies on the conditions of human skin relevant to bitemark-analysis;
- an ability to exploit the existing accumulated dermatological knowledge;
- experimental studies on the behaviour of regularly observed characteristics on objects with geometric and viscoelastic properties similar to human skin;
- experimental studies on how sets of such characteristics observed of biting-mechanisms or their bitemarks on flat objects with low viscoelasticity interact with corresponding characteristics observed on bitemarks on objects with geometric and viscoelastic properties similar to human skin;
- any kind of study relevant to the diagnostic criterion of simultaneity between a bitemark and a control-injury known to be relevant to a legal injury; and
- a theoretical or methodological discourse on appropriate inference strategy for either the purpose of general knowledge or the purpose of forensic diagnosis.

This state of knowledge and level of consensus, given all the years in which forensic bitemark-analysis has been practiced, is only possible if the bitemark-analysts either (a) can justify that they can and should adhere to epistemological norms and inference-procedures different from those practiced in other expert-disciplines; (b) are simply unaware that there are alternative such norms and procedures; or (c) are aware, but do not understand how alternative such norms and procedures affect their ability to achieve the aims/values of the forensic diagnosis.

The answer to the questions in this chapter must be that very little of the published knowledge on bitemark-production in human skin is relevant to forensic bitemark-diagnosis of bitemarks in human skin — because most of the existing knowledge are not evidence-based to the standard specified in chapter 1 of this dissertation or specified by ABFO (2008). Most of the published knowledge is produced according to a standard which I in the two previous chapters called "incomplete/open induction". This standard implies (1) that the reference-bases for the conclusions about the likelihood of the

suspected hypothesis are left unspecified, which in turn leaves the likelihood for the suspected hypothesis ambiguous; and, not the least, (2) that the crime investigator will be prevented from using the so far only existing unambiguous means for assessing the risk of wrong conclusions — which in turn prevents the crime investigator from assessing the risk of having contributed to cause consequences all agree should be avoided: That an innocent is convicted or a guilty is acquitted.

A crime investigator should therefore not expect that a given bitemark-expert's diagnosis of a bitemark on human skin will be evidence-based, or in other words, provide the information necessary for the investigator to assess whether the risk of a wrong conclusion is sufficiently low for the purpose of the investigation.

The main question of this second part of the dissertation has been whether European crime-investigations of bitemark-means are evidence-based. I have investigated this question via two sets of information: (1) The repeated investigations of the bitemark-means in the Torgersen-case as this was expressed in mainly the court-appointed bitemark-experts and (2) the knowledge production on bitemarks in human skin as this was expressed in published knowledge produced by bitemark-experts. I suggest that one may with reasonable confidence conclude that European *bitemark-experts' diagnoses* of bitemarks in human skin, more likely than not, will not be evidence-based to the standard of Premise 1 in this dissertation. Can we be equally confident that the same conclusion applies to crime investigative decisions about bitemark-means? It is difficult to imagine how an evidence-based crime investigator could continue to request assistance from experts which did not provide the information they needed. It is more likely that the two professions share the same standard of inference. This would also be consistent with the inference-standard required by jurists and judges during the trial-phase of a crime-case.

I thus also suggest that one may with reasonable confidence conclude that European crime investigations of bitemark-means more likely than not will not be evidence-based to the standard identified in this chapter. Again, this does *not* mean that their conclusions about the relevance of bitemark-means are always wrong. The conclusions may be correct or wrong — but by not being evidence-based there will be no inter-subjective means by which someone else than the crime investigator can assess that question. This independent assessment may not have been frequently asked for in the past. But it was asked for in the Torgersen-case, and it will be asked for in the

future.

The final part of this dissertation will be more constructive: An evidence-basing methodology is suggested which is compatible with the epistemological conditions and aims of crime investigation; a model of the crime investigative bitemark-problem will be constructed and exemplified; and a practical guideline for investigative bitemark-problems is suggested.

# Part III

## Evidence-basing bitemark-means of evidence: A Bayesian theoretical Approach

The studies in the previous chapter suggest that we should not expect that European crime investigative decisions about the evidential value of bitemark-means are evidence-based — not to the standard of Premise 1 in this dissertation nor to the standard recommended by academic institutions and the main organization for forensic odontologists: The reason is that forensic odontologists and, most likely, crime investigators prefer to adhere to the inference-norm of "incomplete and open induction" rather than to "complete and closed induction" when they assess the significance of their observations. The former norm conserves the attention on the suspected hypothesis and leaves the attention to alternative possible hypotheses unstructured — which in turn allows for passive/implicit, impulsive, and subjective choice of reference-groups and -terms. The effects are that (a) the public is prevented from assessing the reasonableness of the investigators and experts decisions and (b) the public as well as the investigators/experts, themselves are prevented from assessing whether the aims and values of the criminal case process have been adequately protected and not undermined. The strong want to avoid wrong decisions which may undermine important aims and values is perhaps the single most important reason why academic institutions insist that empirical investigations should be subject to the norm of "complete and closed induction". This norm structures the investigators reasoning — forces him/her to specify unambiguously the content of the negation of the suspected hypotheses, assess the probability and significance of the observations in the case the negation-hypothesis were to be true as well as in the case the suspected hypothesis were to be true. This norm is difficult to challenge: it has survived as the best means, so far, by which to avoid wrongful decisions over time.

In this last part of the dissertation I will suggest a Bayesian theoretical methodology as an alternative strategy when assessing and deciding about the basic, causal-logical relevance or evidential value of case-specific legal bitemark-means. The question in this part is

### **Question 3: A possible alternative procedure for bitemark-**

**means** The Bayesian theoretical methodology is justifiably able to protect the analytical and crime-investigative aims and values of the bitemark-problem. But is it justifiably able to achieve and protect the broader legal-institutional, *criminal case processual*, aims and values?

In **Chapter 9** I present a subjectivist or personalistic Bayesian Network approach ( $BN_s$ ) as a possible alternative. The epistemological concepts and

technical heuristics of BN<sub>s</sub> is introduced, explained, and specified, and argued to be adequately accounting for the *epistemological* conditions and aims of the crime investigative decision.

In **Chapter 10** I proceed to specify the kind of bitemark-problem to be modelled in the terms of Bayesian Decision Theory. The first part specifies the context, the relevant events, the relevant consequences, and the decision-options of the problem. This provides the basis for the expression of the bitemark-problem as a utility-function. Secondly, the likelihood-ratio is suggested used by the crime investigator as an indicator of the value of the expert-information with respect to the diagnostic criteria involved in the problem. Thirdly, a general likelihood-ratio for the bitemark-problem is suggested and justified, and a general utility-function for the bitemark-problem is specified.

In **Chapter 11** I perform a BN<sub>s</sub>-analysis of a crime-investigative bitemark-problem approximating that of the Torgersen-case. Borrowing the reality of the case, it will be assumed (a) that four markers were used for the expert-diagnosis of the most likely causal biting-mechanism of the bitemark and that these have certain distributions; (b) that a joint set of both case-particular and expert-knowledge markers was used for the diagnosis of simultaneity between the legal injury and the bitemark and that this has a certain distribution; and (c) that the experts have a certain diagnostic accuracy when using these markers for the two diagnostic purposes. The likelihood-ratio for the problem is calculated and interpreted and I demonstrate how different reference-classes affect the posterior probabilities.

In **Chapter 12** I relate the suggested BN<sub>s</sub>-solution to the crime investigative bitemark-problem to the worries held by opponents to formal approaches to evidence-assessment in the legal context. These worries are concluded to be far less relevant when the BN<sub>s</sub>-approach is restricted to the decisions at the investigative level. If Premise 2 and Premise 3 are reasonable then the investigative decisions should not under-communicate uncertainty — quite the contrary: Crime-investigative knowledge is then expert-knowledge just like any other expert-knowledge and not only can but also should adopt a methodology which routinely induces assessments of the risks of propagating false beliefs.

The dissertation ends by suggesting a basic guideline to crime investigators with a bitemark-problem similar to the one specified in Chapter 11. This guideline specifies the minimum set of questions the crime investigator needs to assess and answer for such problems in order for the decision

about basic relevance or evidential value to be evidence-based. The guideline includes the questions needed answered by the bitemark-experts and the medical examiners as well.

# Chapter 9

## Bayesian Networks with a Subjectivist notion of Probability, $\mathbf{BN}_s$

In this chapter I present the norms central to Bayesian theories of justification and to Bayesian methodologies; and I present the notation and definitions required for the modeling of the crime-investigative bitemark-problem. I will do so in the terms of Bernardo and Smith's *Bayesian Theory* (2000). The epistemological norms are the topic of the first section. The second section presents the axiomatic basis for the methodologies of Bayesian decision-analysis and Bayesian Networks. I will in the following denote these two methodologies by  $\mathbf{BN}_s$ , the subscript referring to the subjectivist notion of probability assumed when I apply the methodology of Bayesian Networks. In the third section I introduce and define two sets of concepts crucial to  $\mathbf{BN}_s$ : Belief, uncertainty, and probability; and preference, consequence, and utility. In the last section I will explicate the graph-theoretical component of  $\mathbf{BN}_s$  and discuss briefly the epistemic and pedagogic contribution of this heuristic.

### 9.1 Introduction

All inferences — whether from the particular to the general or from the general to the particular, and independent of the number of individuals — need to use four kinds of logical connectives: Conjunction, disjunction, implica-

tion, and negation. As explicated in chapter 2, the criterion of validity for *deductive* arguments by these connectives are clear: If the premises are true then the implication is true as well. But the criterion of soundness for *inductive* arguments via these connectives is less clear: It was possible to identify *reliability*, *relevance*, and *coherence* as necessary components of soundness, but conflict remains about the exact meaning of these sub-criteria. Several suggestions exist, even for those situations where one needs to move between the particular and the general for only a limited number of units. I referred to one of these suggestions, that of Savage (1954/1972).

$\mathbf{BN}_s$  agrees epistemologically with Savage (1954/1972) and shares the same problem: What are the criteria for sound discrimination between alternative decision-possibilities in a given problem? The main important difference between  $\mathbf{BN}_s$  and the proposal of Savage (1954/1972) is that he former exploits a heuristic from graph-theory when assessing and justifying a suggested causal relationship among the variables identified as relevant for a given decision-problem. The general Bayesian Networks-approach — a BN-approach without a subscript — does not presume a subjectivist notion of probability nor a Bayesian epistemology, but does not preclude so either. The "Bayesian" in Bayesian networks refers to a heuristic exploited by Savage (1954/1972) as well — namely Thomas Bayes's (1702-1761) solution for assessing *inverse probability*: *Bayes Rule* or *Theorem*(Bayes 1763, in Pearson and Kendall (eds.) 1970:131-153). Bayes' Rule is useful in situations where the investigative question is about the probability of an abduced hypothesis conditional on a particular set of observations (as opposed situations in which the question is about the probability of a set of observations conditional on an assumed probability or density function for the suggested relationship). The idea that probability can/should be interpreted as personal or subjective degree of belief as well as or rather than objective or relative frequency is a much later idea. The reason, then, for using Bayesian Networks instead of Savage's proposal is that the former exploits *graph theory* in addition to probability theory when justifying a particular model of a problem. The latter is useful when an inference problem becomes complex and/or if there is a particular need to standardize decision-performance when a given kind of inference problem tend to recur.

Both complexity and recurrence are basic characteristics of the decision-problem of this dissertation — of assessing and deciding about the evidential value of a bitemark-means. A third characteristic of the bitemark-problem is that it concerns propositions about highly conditioned events — events

being a singular outcome of a causal process with unknown properties. This "forces" the investigator to ask the kind of question typically addressed by Bayesian Networks: "What are the likelihoods of the alternative hypotheses given this set of information?". A fourth characteristic of the problem is that the decision-maker almost completely lacks expert-knowledge in the form of results from larger scale studies using standard statistical techniques. The third and the fourth characteristic exclude the kind of question typically addressed by regular scientists: "What is the probability of having these observations conditional on this hypothesis and these randomly selected individuals?". The investigator with a bitemark-problem has, typically, only access to experts' *personal experience* about the phenomenon in question. This more or less inter-subjective experience, just like the data of a large scale study, must of course also be *accredited* — it must be assessed for its degree of soundness: Is the experience sufficiently reliable, relevant, and coherent for its intended purpose?

So, if it is agreed that the crime-investigative bitemark-problem involves inference and decision under uncertainty and if it is agreed that such inferences need to be sufficiently sound because of the serious consequences,  $\mathbf{BN}_s$  is a possible methodology by which to ensure such soundness strategically, across decision-makers and particular cases.

## 9.2 The Bayesian epistemological basis of $\mathbf{BN}_s$

For the presentation of the Bayesian-epistemological fundament of  $\mathbf{BN}_s$  I have chosen to stay rather close to the account provided by Bernardo and Smith in their *Bayesian Theory* (2000).

This means that I will interpret the investigator's problem of deciding the evidential value of a bitemark on human skin as a practical **decision-problem** within a given **context**. The latter consists of previous knowledge of the investigator — in terms of (a) his or her experiences with similar cases and situations and (b) his or her obligations to adhere to the institutional and organizational values, norms, procedures, and instructions governing the processing of crime-cases in the investigative phase. This context is seen as the investigator's initial state of mind or reference-structure: It will condition the way and content by which he/she organizes, assesses, and decides about

the new case. This contextual background knowledge will be denoted by  $K_0$ .

A decision-problem will be defined as follows:

**Definition 9.1. (Decision problem).**

A decision-problem will be defined by the elements  $(\mathcal{E}, \mathcal{C}, \mathcal{A}, \leq)$ , where

- (i)  $\mathcal{E}$  is an algebra of relevant events,  $E_j$ ;
- (ii)  $\mathcal{C}$  is a set of possible consequences,  $c_j$ ;
- (iii)  $\mathcal{A}$  is a set of options, or potential acts, consisting of functions which map finite partitions of  $\Omega$ , the certain event in  $\mathcal{E}$ , to compatibly-dimensioned ordered sets of elements of  $\mathcal{C}$ ;
- (iv)  $\leq$  is a preference order, taking the form of a binary relation between some of the elements of  $\mathcal{A}$ . Bernardo and Smith (2000:18-19)

### 9.2.1 The events relevant to a decision-problem

The basic framework for the interpretation of the content of propositions or claims involved in the investigator's inference or decision-problem will be that of Boolean algebra: The content of single propositions will be seen as events, denoted by capital letters  $E, F, \dots$  — each having a finite number of mutually exclusive states, denoted by lower case letters,  $e, f, \dots$  — which belong to the finite universe of events,  $\mathcal{E}$ . The certain event will be denoted by  $\Omega$  and the impossible or empty event by  $\emptyset$ , both belonging to  $\mathcal{E}$ .

States and events relate to each other by the following notation:

- $e \in E$  —  $e$  is an element or state of the event  $E$ .
- $E \subset F$  (or  $F \supset E$ ) — every element in  $E$  is contained in  $F$
- $E = F$  —  $E$  and  $F$  have exactly the same kind and number of elements.

Events can be constructed or deconstructed according to the following set of basic rules (a selection):

- $\neg E$  — the **complement** of  $E$  with respect to  $\mathcal{E}$
- $\cup_i e_i$  — the **union** of the elements of  $E$
- $E \cup F$  — the union of the elements in  $E$  and the elements in  $F$  (either  $E$  or  $F$ )

- $E \cap F$  — the **intersection** of elements which occurs in both  $E$  and  $F$
- $\mathcal{E} \cap E = E$ ,  $\mathcal{E} \cup E = \mathcal{E}$
- $\emptyset \cap E = \emptyset$ ,  $\emptyset \cup E = E$
- $E \cap E = E = E \cup E$ ,  $E \cap (\neg E) = \emptyset$ ,  $E \cup (\neg E) = \mathcal{E}$
- $E \cup F = F \cup E$  and  $E \cap F = F \cap E$  — **commutativity**
- $E \cup (F \cup G) = (E \cup F) \cup G$  and  $E \cap (F \cap G) = (E \cap F) \cap G$  — **associativity**
- $E \cup (E \cap G) = E$  and  $E \cap (E \cup F) = E$  — **absorption**
- $E \cup (F \cap G) = (E \cup F) \cap (E \cup G)$ , and
- $E \cap (F \cup G) = (E \cap F) \cup (E \cap G)$  — **distributivity**

As said, the context  $K_0$  of the investigator is seen to condition both the way and *content* by which he or she assesses and decides about a new case —  $K_0$  thus determines which events which are **relevant** to the decision-problem. This is then why  $\mathcal{E}$  in (i) is said to contain *relevant* events  $E_i$ . The property of relevance needs much more precision and substance than this, but I want to define it in terms of the consequences and the relation  $\leq$  of the decision-problem and will wait until these elements have been treated (a fuller concept of relevance will be offered in connection with the treatment of the graph-theoretical component of the Bayesian Network-approach).

### 9.2.2 The consequences of a decision

$\mathcal{C}$  is the set of possible consequences the investigator needs to take into consideration during the assessment of the bitemark-problem. A decision to choose this or that particular evidential value for a bitemark may either be correct — which realizes the intended aims, or it may be wrong — which does not realize the intended aims, but something else. I have several times described the content of the most important consequences of crime-investigative decisions. The consequences of the bitemark-problem will be further specified below and in the next chapter. The basic preference-structure among consequences of decisions in general as well as their relation to the events specified for a decision-problem will be returned to below.

### 9.2.3 The options available to the crime-investigator

$\mathcal{A}$  is the set of actions or *decision-options* available to the decision-maker. In the bitemark-problem the investigator is to decide about the evidential value

of a bitemark-means: In principle a bitemark-means may have any evidential value relative to a given indictment. In practice it is finite and possible simply dichotomous, deciding either that the bitemark-means is *positively relevant* or *not positively relevant*. Any possible decision is in principle available to the investigator in any bitemark-problem and are the problem-particular set of decision-options generally denoted by  $\mathcal{A}$ . The particular content of the options in the bitemark-problem will be specified later.

A human decision to do something will be seen as an act which intervenes in the world and causes it to change. A human act will be seen as an *option*, denoted by  $a$ , being a function which links events to consequences — a linking of a partition of  $\Omega$ ,  $\{E_j, j \in J\}$ , to a corresponding set of consequences  $\{c_j, j \in J\}$ . An event  $E_j$  which leads to consequence  $c_j$  will be denoted by  $\{c_j | E_j\}$ ; and a problem with  $k$  possible options linking  $E_j$  and  $c_j$  will be denoted by  $a_k = \{c_j | E_j\}$ .

#### 9.2.4 A qualitative ranking of Options and events

The fourth basic element of the decision-problem is the relation  $\leq$  between pairs of options in  $\mathcal{A}$ .  $\leq$  is to be interpreted as an *ordering* with certain properties.  $(a_1, a_2) \in \mathcal{A}$ :

##### Definition 9.2 (Binary relations)

If  $a_1$  is not preferred to  $a_2$  this will be expressed as  $a_1 \leq a_2$

- (i)  $a_1 \sim a_2 \iff a_1 \leq a_2$  and  $a_2 \leq a_1$
- (ii)  $a_1 < a_2 \iff a_1 \leq a_2$  and it is not true that  $a_2 \leq a_1$
- (iii)  $a_1 \geq a_2 \iff a_2 \leq a_1$
- (iv)  $a_1 > a_2 \iff a_2 < a_1$  (Bernardo and Smith (2000:20))

An individual consequence of an option can be identified as a special case of options:  $c = \{c | \Omega\}$ , for any  $c \in \mathcal{C}$ .  $c$  will denote either an element of  $\mathcal{C}$  or the element  $\{c | \Omega\}$  of  $\mathcal{A}$  (Bernardo and Smith 2000:20) To save on notation  $\leq$  will also be used to indicate the binary relation between individual consequences of options: If, and only if,  $\{c_1 | \Omega\} \leq \{c_2 | \Omega\}$  this will be written  $c_1 \leq c_2$  and say that consequence  $c_1$  is not preferred to consequence  $c_2$ .

$\leq$  will further (again to economize) be used to define a binary relation on  $\mathcal{E} \times \mathcal{E}$ , the collection of all pairs of relevant events, to capture the notion of one event being more likely than another .

### Definition 9.3 (*Uncertainty relation*)

$$E \leq F \iff \text{for all } c_1 < c_2, \{c_2 \mid E, c_1 \mid \neg E\} \leq \{c_2 \mid F, c_1 \mid \neg F\};$$

we then say that *E* is **not more likely** than *F*. (Bernardo and Smith (2000:21))

The implications from Definition 9.2 will be seen to describe uncertainty relations between events as well.

It is important to stress again that preferences between options (as well as preferences between consequences and between events) are always considered *conditional* on the investigator's initial state of knowledge and organizational and institutional values, norms, procedures, and instructions — denoted by  $K_0$ . When the investigator opens a new investigation he or she will have to account for the new information. If  $G$  is a new event assumed to have occurred, preferences between options must be described by a new binary relation,  $\leq_G$ , which includes both  $K_0$  and the additional information provided by  $G$ . The relation between  $\leq$  and  $\leq_G$  is given by the following:

### Definition 9.4. (*Conditional preference*).

For any  $G > \emptyset$ ,

- (i)  $a_1 \leq_G a_2 \iff \text{for all } a \{a_1 \mid G, a \mid \neg G\} \leq \{a_2 \mid G, a \mid \neg G\};$
- (ii)  $E \leq_G F \iff \text{for all } c_1 \leq_G c_2 \{c_2 \mid E, c_1 \mid \neg E\} \leq_G \{c_2 \mid F, c_1 \mid \neg F\};$

If  $a_1$  is not preferred to  $a_2$  if  $G$  has occurred, then preference carries over to any pair of options leading, respectively, to  $a_1$  or  $a_2$  if  $G$  occurs and defined identically if  $\neg G$  occurs.

## 9.3 The decision-theoretical framework — the axiomatic basis of $\text{BN}_s$

To have precise assumptions about the elements of the above qualitative basis Bernardo and Smith (2000) offer five axioms which will be stated here. They are to be seen as prescriptive — as what a decision-maker *should* (and *can*) do if it is considered important to achieve certain aims/values. They are thus *not* aspiring to describe the ways human beings reason generally.

The first axiom states that the consequences involved in a given decision-problem should be *comparable*:

**Axiom 1. (*Comparability of consequences and dichotomized options*)**

- (i) There exist consequences  $c_1, c_2$  such that  $c_1 < c_2$ .
- (ii) For all consequences  $c_1, c_2$ , and events  $E, F$ ,  
either  $\{c_2 \mid E, c_1 \mid \neg E\} \leq \{c_2 \mid F, c_1 \mid \neg F\}$   
or  $\{c_2 \mid E, c_1 \mid \neg E\} \geq \{c_2 \mid F, c_1 \mid \neg F\}$   
(Bernardo and Smith (2000;23)).

This axiom states that the decision-maker having to choose among alternative options should be willing to express preference between consequences: A crime-investigator having to decide whether a bitemark-means is positively relevant or not to a given indictment must thus be willing to express preferences among the following possible consequences: Having contributed to (a) convict a guilty person, (b) convict an innocent person, (c) acquit an innocent person, or (d) acquit a guilty person.

The second axiom states that the preferences among options should be *transitive*:

**Axiom 2. (*Transitivity of preferences*)**

- (i)  $a \leq a$
- (ii) If  $a_1 \leq a_2$  and  $a_2 \leq a_3$ , then  $a_1 \leq a_3$   
(Bernardo and Smith (2000;24)).

A useful consequence of the above:

**Proposition 9.1. (*Transitivity of uncertainties*)**

- (i)  $E \sim E$
- (ii) If  $E_1 \leq E_2$  and  $E_2 \leq E_3$ , then  $E_1 \leq E_3$   
(Bernardo and Smith (2000;25)).

Axiom 2 and Proposition 9.1 state that a decision-maker following it would ensure coherency concerning his/her preferences among options and events. The message of Axiom 2 seems obvious, but staying true to it during practical case-work is not easy. The events as well as concerns are numerous and complexly inter-acting, and new more or less relevant events and

concerns will interfere: Confusion and temptation are constant challenges to any individual's ability to stay transitive. Anyone having tried to lose weight or quit smoking (or write a Ph.D.) knows clearly what it takes, yet knows too how difficult it is in practice. Embodying this axiom or rather this *epistemological norm* in the methodology may thus assist the individual decision-maker trying to achieve certain aims/values.

A third axiom concerns the *consistency* among the preferences:

**Axiom 3. (consistency of preferences)**

- (i) *If  $c_1 \leq c_2$  then, for all  $G > \emptyset$ ,  $c_1 \leq_G c_2$ .*
- (ii) *If, for some  $c_1 < c_2$ ,  $(c_2 \mid E, c_1 \mid \neg E) \leq (c_2 \mid F, c_1 \mid \neg F)$ , then  $E \leq F$ .*
- (iii) *If, for some  $c$  and  $G > \emptyset$ ,  $(a_1 \mid G, c \mid \neg G) \leq (a_2 \mid G, c \mid \neg G)$ , then  $a_1 \leq_G a_2$*   
(Bernardo and Smith (2000:27))

This axiom states that preferences between pure consequences should only be dependent on the "relative likelihood" of  $E$  and  $F$  and not on the particular consequences used to construct the options. One important implication of Axiom 3 is that preferences between consequences are invariant under changes of the origin of information on the events of the problem:

**Proposition 9.2. (Invariance of preferences between consequences)**

$c_1 \leq c_2$  if and only if there exist  $G > \emptyset$  such that  $c_1 \leq_G c_2$   
(Bernardo and Smith (2000:27)).

A second implication of Axiom 3 is that the uncertainty ordering of events respect logical implications:

**Proposition 9.3. (Monotonicity)**

*If  $E \subseteq F$  then  $E \leq F$*   
(Bernardo and Smith (2000:27))

That we are able to say that if  $E$  logically implies  $F$ , then  $F$  cannot be considered less likely than  $E$ , will be a key property in the next chapter's effort to solve the crime-investigator's problem of deciding about the

evidential value of a bitemark. This *logical* relationship is, for some of the connections in the decision-problem modelled, the only means by which to elicit independence structures.

We may also already now exploit this relationship between logic and uncertainty-orderings to define what it will mean to have pairwise independence of events:

**Definition 9.5 (Pairwise independence of events).**

*E* and *F* are (pairwise) independent, denoted  $E \perp F$ , if, and only if, for all  $c, c_1, c_2$

- (i)  $c \bullet \{c_2 \mid E, c_1 \mid \neg E\} \Rightarrow c \bullet_F \{c_2 \mid E, c_1 \mid \neg E\}$ ,
- (ii)  $c \bullet \{c_2 \mid F, c_1 \mid \neg F\} \Rightarrow c \bullet_E \{c_2 \mid F, c_1 \mid \neg F\}$ ,

where  $\bullet$  is any one of the relations  $<$ ,  $\sim$  or  $>$   
(Bernardo and Smith 2000:28).

The suggestion that the investigator should ensure that the preference and uncertainty relations between consequences and events adhere to the above axioms are a suggestion to adhere to a set of epistemological *norms*: If the investigator adhere to these norms he/she will be *coherent* or *consistent* given the context  $K_0$  and the particular decision-problem during the assessment and the decision to choose this or that option as the solution to the decision-problem. The normative aspect of these properties needs perhaps some stressing. They are *not* descriptions of actual human reasoning. They might have been descriptive because humans certainly *can* reason according to these rules and will also do so if problems are sufficiently transparent. But we may not expect humans to reason according to the axioms when the problems become more complex. To ensure predictable achievement of aims/values across individual decision-makers and cases one may embed these norms in the inference-procedures of problem solving.

Under the methodology of **BN<sub>s</sub>**, all the order-relations between the consequences and events of a decision-problem will be seen to be *personal*: This will mean that the decision-maker is free to express his/her own preference and uncertainty structure given the conditions imposed by the context  $K_0$ . This subjectivity is less radical than it seems: It will be presumed that (a) an investigator is normally equipped with logical, emotional, and social intelligence; (b) he/she actually do oblige by the organizational and institutional norms and instructions of the context in which these assignments are

performed and which are specified in  $K_0$ ; (c) the content of the propositions involved should be interpreted as elements of a finite space of possibilities; (d) the all the *relevant* events and consequences given  $K_0$  and the new particular problem is identified and specified and that only these will be considered during the analysis; and (e) that the investigator's orderings should have the coherency-properties of the axioms above. These presumptions ensure *inter-subjectivity* and are simply not compatible with the kind and degree of disintegration sometimes claimed to be the result of allowing personal judgements of probability.

It is not difficult to see how frequency- or model-based uncertainty-assignments have something extra which makes at least me have more confidence in them — namely the actual ability to repeatedly test, and independently so, any claim of association under known conditions. The number of times you experience two characteristics occurring together will increase your degree of confidence that there is some kind of association between these two characteristics. This will never be denied by Bayesians. But there are situations in which repeated trials are not possible — like for the claims about associations made by a crime-investigator or a medical diagnostician. The question is how confidence can be established for claims in these situations as well. The traditional solution is personal authority: A claim is trustable if is made by a person appropriately trained and/or experienced. This solution is still practiced for more or less good reasons, but I have already argued why other solutions should be sought for public decisions. To suggest the methodology of  $\mathbf{BN}_s$  to the decision-maker of public decisions is to suggest that certain necessary confidence-installing aspects of the traditional scientific methodologies can and should be required: The crime-investigator cannot repeat trials to test his/her hypotheses, but he/she can still aspire the epistemological norms presumed for such repeated trials and implement these by adhering to known rules of logic — by adhering to the axioms identified above.

The above norms are then the basic necessary elements of this dissertation's concept of evidence-basis, and are the norms I suggest can and should be respected during crime-investigative assessments about the value of means of evidence. In the next section I introduce certain heuristics which may be exploited if one accepts and respects the above axioms and their epistemological purpose.

## 9.4 Managing uncertainty and value of consequences within BN<sub>s</sub>: Probability and Utility

Bernardo and Smith (2000:29) argue that there is an analogy between  $\leq$  and a number of qualitative relations used in everyday language — such as hotter than, heavier than, not hotter than, and not heavier than, more probable than, not more probable than, etc. These relations exist in any social language and can well be communicated without numbers attached. Yet, we will usually have no problems attaching standard numeric scales to express more precisely how much more (or less) hot, heavy, or probable something is compared to another something. Any such quantification presumes the existence of a coherent qualitative ordering relation as specified in the above subsection.

Bernardo and Smith (2000) argue further that it is possible to have a *standard option* having close links to more familiar numerical scales such as kilogram and metre and which may play an analogous role to these. The first step is to assume the following about the algebra  $\mathcal{E}$ :

**Axiom 4. (Existence of standard events).**

There exists a subalgebra  $\mathcal{S}$  of  $\mathcal{E}$  and a function  $\mu : \mathcal{S} \rightarrow [0, 1]$  such that:

- (i)  $S_1 \leq S_2$  if, and only if,  $\mu(S_1) \leq \mu(S_2)$ ;
- (ii)  $S_1 \cap S_2 = \emptyset$  implies that  $\mu(S_1 \cup S_2) = \mu(S_1) + \mu(S_2)$ ;
- (iii) for any number  $\alpha$  in  $[0, 1]$ , and events  $E, F$ , there is a standard event  $S$  such that  $\mu(S) = \alpha$ ,  $E \perp S$  and  $F \perp S$ ;
- (iv)  $S_1 \perp S_2$  implies that  $\mu(S_1 \cap S_2) = \mu(S_1)\mu(S_2)$ .
- (v) if  $E \perp S$ ,  $F \perp S$  and  $E \perp F$ , then  $E \sim S \Rightarrow E \sim_F S$  (Bernardo and Smith (2000:29)).

Collections of disjoint standard events are then proposed to be as follows:

**Proposition 9.4. (Collections of disjoint standard events).** For any finite collection  $\{\alpha_1, \dots, \alpha_n\}$  of real numbers such that  $\alpha_i > 0$  and  $\alpha_1 + \dots + \alpha_n \leq 1$  there exists a corresponding collection  $\{S_1, \dots, S_n\}$  of disjoint standard events such that  $\mu(S_i) = \alpha_i$ ,  $i = 1, \dots, n$  (Bernardo and Smith (2000:31)).

And the last axiom required concerns the precise measurements of preferences and uncertainties:

**Axiom 5. (*Precise measurement of preferences and uncertainties*).**

- (i) *If  $c_1 \leq c \leq c_2$ , there exists a standard event  $S$  such that  $c \sim \{c_2 \mid S, c_1 \mid \neg S\}$ .*
- (ii) *For each event  $E$ , there exists a standard event  $S$  such that  $E \sim S$  (Bernardo and Smith (2000:31)). .*

### 1. Formal definitions of *degrees of belief* and *degrees of want*

A crime-investigator's choice among the options of the decision-problem in this dissertation — deciding whether or not a bitemark-means is positively relevant to a given indictment — should be determined by both (a) the *uncertainties* attached to the events relevant to the bitemark-problem and (b) the possible consequences of deciding correctly or incorrectly with respect to the aims/values intended by the decision. In this subsection I will first provide a formal definition of degrees of beliefs, providing a numerical measure of the uncertainty associated with the occurrence of events. Secondly, I will provide a formal definition of degrees of want, providing a numerical measure of the value associated with the possible consequences. By these heuristics the crime-investigator may assess the relative probability of all the possible consequences in a given decision-problem: The probability of correctly deciding the bitemark-means to be positively relevant or not and the probability or *risk* of incorrectly deciding so.

#### a.) belief and probability

Bernardo and Smith (2000) establish some basic results concerning the uncertainty relation between events. As a consequence of Axiom 5 the uncertainty relation between events is *complete*;

**Proposition 9.5. (*Complete comparability of events*).**

*Either  $E_1 > E_2$ , or  $E_1 \sim E_2$ , or  $E_2 > E_1$  (Bernardo and Smith 2000:33); and*

**Proposition 9.6. (Additivity of uncertainty relations).**

If  $A \leq B$ ,  $C \leq D$ , and  $A \cap C = B \cap D = \emptyset$ , then  $A \cup C \leq B \cup D$ . Moreover, if  $A < B$  or  $C < D$ , then  $A \cup C < B \cup D$  (Bernardo and Smith 2000:34).

Then Bernardo and Smith (2000) offer a definition of a quantitative measure of degree of belief:

**Definition 9.6. (Measure of degree of belief).**

Given an uncertainty relation  $\leq$ , the **probability**  $P(E)$  of an event  $E$  is the real number  $\mu(S)$  associated with any standard event  $S$  such that  $E \sim S$  (Bernardo and Smith 2000:33).

These probabilities are, as said, interpreted as personal degrees of belief, numerical representations of the decision-maker's personal uncertainty relation  $\leq$  between events given  $K_0$ .

**Proposition 9.7. (Existence of uniqueness).**

Given an uncertainty relation  $\leq$  there exists a unique probability  $P(E)$  associated with each event  $E$ .

**Proposition 9.8. (Compatibility).**

A function  $f : \mathcal{E} \rightarrow \mathbb{R}$  is said to be compatible with an order relation  $\leq$  on  $\mathcal{E} \times \mathcal{E}$  if, for all events,

$$E \leq F \iff f(E) \leq f(F)$$

**Proposition 9.9. (Compatibility of probability and degrees of belief).**

The probability function  $P(\cdot)$  is compatible with the uncertainty relation  $\leq$

The following proposition is argued by Bernardo and Smith (2000:35) to be of fundamental importance as it states that coherent, quantitative degrees of belief have the structure of a finite additive probability measure over  $\mathcal{E}$ :

**Proposition 9.10. (Probability structure of degrees of belief).**

$P(\emptyset) = 0$  and  $P(\Omega) = 1$ .

If  $E \cap F = \emptyset$ , then  $P(E \cup F) = P(E) + P(F)$ .

$E$  is significant if and only if  $0 < P(E) < 1$ .<sup>1</sup>

**Corollary. (Finitely additive structure of degrees of belief).**

(i) If  $\{E_j, j \in J\}$  is a finite collection of disjoint events, then

$$P\left(\bigcup_{j \in J} E_j\right) = \sum_{j \in J} P(E_j).$$

(ii) For any event  $E$ ,  $P(\neg E) = 1 - P(E)$ .

Bernardo and Smith (2000) suggest the above to be the justification why formally coherent, quantitative measures of uncertainty must take the form of probabilities. Throughout the rest of this dissertation I will assume this justification to hold: Whenever I use the term of probability I include coherent degrees of belief.

Bernardo and Smith (2000) offer the further definitions and propositions of general probability calculus relevant for the kind of inferences which will be needed later in this dissertation:

**Definition 9.7. (Probability distribution).**

If  $\{E_j, j \in J\}$  form a finite partition of  $\Omega$ , with  $P(E_j) = p_j, j \in J$ , then  $\{p_j, j \in J\}$  is said to be a probability distribution over the partition (Bernardo and Smith (2000:36)).

This means that the total belief ( $\Omega$  being 1) is distributed among the events of the partition,  $\{E_j, j \in J\}$ , according to the relative degrees of belief  $\{p_j, j \in J\}$ , with  $\sum_j P(E_j) = 1$  (Bernardo and Smith (2000:37)).

Pairwise independence of events was above defined (Definition 9.6.) in terms of  $\leq$  and denoted by  $\perp$ . This is argued to be compatible with the standard calculus definition:

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<sup>1</sup>Significant events are events which are practically possible but not certain: An event is significant given  $G > \emptyset$  if  $c_1 <_G c_2$  implies that  $c :_1 <_G \{c_2 \mid E, c_1 \mid \neg E\} <_G c_2$ . If  $G = \Omega$ ,  $E$  will be said to be significant; **Proposition:** An event  $E$  is significant given  $G > \emptyset$ , if and only if  $\emptyset < E \cap G < G$ . In particular,  $E$  is significant if and only if  $\emptyset < E < \Omega$ . (Bernardo and Smith 2000: 27)

**Proposition 9.11. (*Characterization of independence*).**

$$E \perp F \iff P(E \cap F) = P(E)P(F)$$

(Bernardo and Smith (2000:37)).

To assess the relevance of multitude of simpler events relevant to the complex event expressed by a bitemark-means the investigator may exploit the rule of conditional probability as defined in standard probability calculus:

If the conditional beliefs are such that  $E \leq_G F \iff E \cap G \leq F \cap G$  and if there exist  $c_1 < c_2$  such that  $\{c_2 \mid E, c_1 \mid \neg E\} \leq_G \{c_2 \mid F, c_1 \mid \neg F\}$  and if  $P(E \mid G)$  provides a quantitative measure of the uncertainty attached to  $E$  given the assumed occurrence of  $G$  (and  $K_0$ ), then a question about the relevance between  $E$  and  $G$  can be assessed in the terms of the following rule:

**Proposition 9.12. (*Conditional probability*).**

For any  $G > \emptyset$

$$P(E \mid G) = \frac{P(E \cap G)}{P(G)},$$

(Bernardo and Smith (2000:39))

where it is claimed that  $E \leq_G F \iff P(E \mid G) \leq P(F \mid G)$ .

Then Proposition 9.11 can then be extended to degrees of belief conditional on the assumed occurrence of significant events:

**Proposition 9.13. (*Probability structure of conditional degrees of belief*).**

For any event  $G > \emptyset$

- (i)  $P(\emptyset \mid G) = 0 \leq P(E \mid G) \leq P(\Omega \mid G) = 1$ ;
- (ii) if  $E \cap F \cap G = \emptyset$ , then  $P(E \cup F \mid G) = P(E \mid G) + P(F \mid G)$ ;
- (iii)  $E$  is significant given  $G \iff 0 < P(E \mid G) < 1$  (Bernardo and Smith (2000:40)).

**Corollary. (Finitely additive structure of conditional degrees of beliefs).**

For all  $G > \emptyset$ ,

(i) if  $\{E_j \cap G, j \in J\}$  is a finite collection of disjoint events, then

$$P\left(\bigcup_{j \in J} E_j \mid G\right) = \sum_{j \in J} P(E_j \mid G);$$

(ii) for any event  $E$ ,  $P(\neg E \mid G) = 1 - P(E \mid G)$  (Bernardo and Smith (2000:40)).

The graph-theoretical component of  $BN_s$ , which will be explicated in the next section, will particularly make use of a special case of Proposition 9.12. First:

**Proposition 9.14.**

For all  $F > \emptyset, E \perp F \iff P(E \mid F) = P(E)$ .

In the case of three events,  $E$ ,  $F$ , and  $G$ , we would regard the degree of belief about  $E$  as being independent of knowledge of  $F$  and  $G$  if and only if  $P(E \mid H) = P(E)$ , for any of the four possibilities for  $H$ :

$$\{F \cap G, F \cap \neg G, \neg F \cap G, \neg F \cap \neg G\}$$

Bernardo and Smith (2000:46) suggest the following definition for *mutual independence* to capture the above perception:

**Definition 9.8. (Mutual independence)**

Events  $\{E_j, j \in J\}$  are said to be *mutually independent* if, for any  $I \subseteq J$ ,

$$P\left(\bigcap_{i \in I} E_i\right) = \prod_{i \in I} P(E_i).$$

And they suggest the following definition for *conditional independence* (Bernardo and Smith 2000:47)

### Definition 9.9. (*Conditional independence*)

The events  $\{E_j, j \in J\}$  are said to be conditionally independent given  $G > \emptyset$  if, for any  $I \subseteq J$ ,

$$P\left(\bigcap_{i \in I} E_i \mid G\right) = \prod_{i \in I} P(E_i \mid G).$$

For any subalgebra  $\mathcal{F}$  of  $\mathcal{E}$ , the events  $\{E_j, j \in J\}$  are said to be conditionally independent given  $\mathcal{F}$  if and only if they are conditionally independent given any  $G > \emptyset$  in  $\mathcal{F}$ .

If coherent degrees of belief combine according to the rules of finitely additive mathematical probability, then the definition above can greatly simplify the specification of subgroups of events within a complex decision-problem. Such simplification will be of great help for the particular decision-problem studied in this dissertation and will constitute a central element of the justification why  $\text{BN}_s$  can function to evidence-base crime-investigative decisions. I find it important to stress that the numerical results may only be used to indicate a relationship between two events — that these are considered relevant to each other — and to indicate the strength of that relationship. So far the definitions have not said anything about the order of the relevant events. In practical inference problems, we usually think in terms of ordered relationships: Either *causal relationships* (where one event is perceived as the cause of the other event, the effect) or *class-relationships* (where one class of things is seen to belong to another more general class of things). This perceived order *will* indeed be expressed simply by the way we construe the rule, when we ask for  $P(E \mid G)$  rather than  $P(G \mid E)$ , but this alone provides no justification for a specific causal or logical order. Nevertheless, the rule and the suggestion of a certain order may be used heuristically to discriminate between hypotheses as possible causes or host-classes of observed effects or subclasses: Either when asking about the probability of observing a certain set of effects/sub-classes conditional on an assumed and specified probability/density function (believed to account for a suggested relationship causal/class-membership) or when asking about the probabilities of alternative causes/classes conditional on a certain specified set of observed effects/sub-classes. For the latter analytical purpose it is common to use a rule derived from the above rule of conditional probability, namely Bayes' rule:

**Proposition 9.15. (Bayes' theorem).**

For any finite partition  $\{E_j, j \in J\}$  of  $\Omega$  and  $G > \emptyset$

$$P(E_i | G) = \frac{P(G | E_i)P(E_i)}{\sum_{j \in J} P(G | E_j)P(E_j)}.$$

In crime-investigation, where the typical question is about the probability of a particular cause of a particular observed event, the rule of conditional probability may be used to calculate the effect of having observed a set of particular simpler events believed or assumed to be relevant. Denoting the event of the causal proposition by  $H_j$   $\{j = 1, 2\}$  (for hypothesis event having occurred (value 1) or not (value 2)) and the set of observed simpler events as  $E_l$   $\{l = 1, \dots, n\}$  (for  $n$  separate sets of information or evidence), the rule of conditional probability could be specified as follows:

$$P(H_1 | E_l, K_0) = \frac{P(E_l | H_1, K_0)P(H_1 | K_0)}{\{P(E_l | H_1, K_0)P(H_1 | K_0)\} + \{P(E_l | H_2, K_0)P(H_2 | K_0)\}}.$$

**Definition 9.10. (Prior, posterior and predictive probabilities)**

If  $\{H_i, i \in I\}$  are mutually exclusive and exhaustive events (hypotheses), then for any event (information),  $E$ ,

- (i)  $P(H_i), i \in I$  (conditioned by  $K_0$ ), are called the **prior probabilities** of the  $H_i, i \in I$ ;
- (ii)  $P(E | H_i), i \in I$  are called the **likelihoods** of the  $H_i, i \in I$ , given  $D$ ;
- (iii)  $P(H_i | E), i \in I$  are called the **posterior probabilities** of the  $H_i, i \in I$ ;
- (iv)  $P(E)$  are called the **predictive probability** of  $E$  implied by the likelihoods and the prior probabilities.

**b.) Consequences and utilities**

As said, a crime-investigator's choice among the options of the decision-problem in this dissertation — deciding whether or not a bitemark-means is positively relevant to a given indictment — should be determined by both (a) the *uncertainties* attached to the events relevant to the bitemark-problem and (b) the possible consequences of deciding correctly or incorrectly with

respect to the aims/values intended by the decision. Above I have provided the formal definition of degrees of beliefs and a numerical measure of the uncertainty associated with the occurrence of events. Now I will provide a formal definition of degrees of want, providing a numerical measure of the value associated with the possible consequences.

Via the measurement framework defined by Bernardo and Smith (2000)'s Axiom 5(i) above, it is also possible to have a direct way of introducing a numerical measure of the value of consequences, so that the consequences can be accounted for in a coherent manner. Bernardo and Smith (2000:49) first characterizes *extreme consequences* by the following definition:

**Definition 9.11. (*Extreme consequences*).**

*The pair of consequences  $c_*$  and  $c^*$  are called, respectively, the **worst** and the **best** consequences in a decision-problem if, for any other consequence  $c \in C$ ,  $c_* \leq c \leq c^*$  (Bernardo and Smith (2000: 49)).*

The consequences in the crime-investigative context and, by extension, the legal context are in the form of persons' legal rights, resources available to other cases, and general legal and a-legal values and principles. Is it possible to say that extreme consequences exist here? Can one in a given case say that  $c_*$  is the worst possible loss of rights, values, and resources, which according to Definition 9.11 would imply that  $c_*$  plus some additional loss is not possible? This value would be difficult to specify in given cases, but in practice and across similar cases one does operate with extreme values. In this dissertation I will thus, heuristically, assume that extreme consequences exist and that the decision-problem of this dissertation — of deciding about the relevance of a bitemark-means — can be seen as a *bounded* one according to Bernardo and Smith (2000: 50), for which a *canonical utility function* for consequences can be defined:

**Definition 9.12. (*Canonical utility function for consequences*).**

*Given a preference relation  $\leq$ , the utility  $u(c) = u(c \mid c^*, c_*)$  of a consequence  $c$ , relative to the extreme consequences  $c_* < c^*$ , is the real number  $\mu(S)$  associated with any standard event  $S$  such that  $c \sim \{c^* \mid S, c_* \mid \neg S\}$ . The mapping of  $u : C \rightarrow \mathbb{R}$  is called the **utility function** (Bernardo and Smith 2000:50).*

A proposition that the utility of a consequence is uniquely defined and remains unchanged by the arrival of new information is justified, Bernardo and Smith (2000) holds, by definition of utility involving comparison among consequences and options constructed with standard events:

**Proposition 9.16. (*Existence and uniqueness of bounded utility*).**

For any bounded decision-problem  $(\mathcal{E}, \mathcal{C}, \mathcal{A}, \leq)$  with extreme consequences  $c^* < c_*$ ,

- (i) for all  $c$ ,  $u(c | c_*, c^*)$  exists and is unique;
- (ii) the value of  $u(c | c_*, c^*)$  is unaffected by the assumed occurrence of an event  $G > \emptyset$ ;
- (iii)  $0 = u(c_* | c_*, c^*) \leq u(c | c_*, c^*) \leq u(c^* | c_*, c^*) = 1$  (Bernardo and Smith 2000:50).

Bernardo and Smith (2000) note that  $u(c | c_*, c^*)$  can be given an operational definition in terms of degrees of belief: If there is a choice between the fixed consequence  $c$  and the option  $\{c^* | E, c_* | \neg E\}$ , for some event  $E$ , then the utility of  $c$  can be thought of as defining a threshold value for the degree of belief in  $E$ , in the sense that values greater than  $u$  would lead the individual to prefer the uncertain option, whereas values less than  $u$  would lead an individual to prefer  $c$  for certain. The value of  $u$  itself corresponds to the indifference between the two options and is the degree of belief in the occurrence of the best rather than the worst consequence (Bernardo and Smith 2000: 51).

This ends the explication of how the values attached to the consequences involved in a decision-problem can have a numerical measure, a *utility*.

But, as said at the start of this section, a crime-investigator's preferences among options of the decision-problem in this dissertation should be determined by *both* the *uncertainties* attached to the events decided relevant for the problem and the *consequences* to the relevant individual legal rights, collective institutional values, and resources. How can one attach an *overall* numerical measure of value to an option? This question remains to be answered before I can end this section on the quantitative aspects of the **BN**s. Bernardo and Smith (2000) suggest the following definition:

**Definition 9.13. (Conditional expected utility).**

For any  $c_* < c^*$ ,  $G > \emptyset$ , and  $a \equiv \{c_j \mid E_j, j \in J\}$ ,

$$\bar{u}(a \mid c_*, c^*, G) = \sum_{j \in J} u(a \mid c_*, c^*) P(E_j \mid G)$$

is the expected utility of the option  $a$  given  $G$ , with respect to the extreme consequences  $c_*, c^*$ . If  $G = \Omega$ , we shall simply write  $\bar{u}(a \mid c_*, c^*)$  in place of  $\bar{u}(a \mid c_*, c^*, \Omega)$  (Bernardo and Smith 2000: 51).

A decision-criterion for bounded decision-problems follows from the assumptions, definitions, and propositions given in the above two sections:

**Proposition 9.17. (Decision criterion for a bounded problem).**

For any bounded decision with extreme consequences  $c_* < c^*$  and  $G > \emptyset$ ,

$$a_1 \leq_G a_2 \leftrightarrow \bar{u}(a_1 \mid c_*, c^*, G) \leq \bar{u}(a_2 \mid c_*, c^*, G)$$

(Bernardo and Smith 2000: 51).

Bernardo and Smith (2000:52) stresses that Proposition 9.17 only establishes a complete ordering of the options considered and will not guarantee the existence of an optimal option for which the expected utility is a maximum. However, they say, in most practical decision-problems the set of options considered will be finite and so a best option (not necessarily unique) will exist. This is also believed to be the case for the crime-investigative decision-problem of this dissertation.

This ends the formal explication of the Bayesian epistemological norms for coherent quantitative comparisons of alternative (bounded) decisions. This framework is one of the two components involved in the analytical strategy of the **BN**<sub>s</sub> which I recommend to the crime-investigator who needs to assess and decide about the relevance of a bitemark-means. I will hold that it is alone constitutes a sufficient justification for the claim that **BN**<sub>s</sub> has evidence-basing power. The second component involved in **BN**<sub>s</sub>, the graph theoretical component, will be introduced in the next section. This component is, I hold, not strictly necessary but explicates and thus corroborates the justification of the analyst's structuring of the decision-problem according to logical and causal relationships.

## 9.5 The graph-theoretical component of $\text{BN}_s$

Graph-theory is a branch of combinatorics with applications in a host of disciplines such as anthropology, computer science, chemistry, psychology, telecommunication, and traffic-management, etc. Its basic language is the same as that of the decision-theoretical framework above: The content of ordinary language propositions about the world is interpreted to be events being elements of algebras in which the elements are related but not necessarily according to a specific order. Thus any kind of relationship between any kind of object is possible: People or animals contacting through verbal/non-verbal communication or physical and mental entities, events, or mechanisms contacting through causality, regular conjunction, or logic.

Following Buckley and Lewinter (2003: 47-48), a graph  $G$  is a formal representation of a given relationship-problem and consists of two sets: A nonempty finite set  $V$  of **vertices** or **nodes** represents the objects and a finite set  $E$  of **edges** constitutes unordered pairs of distinct nodes from  $V$ , signifying dependency relationships. If  $V = v_1, v_2, \dots, v_n$  is a set of  $n$  nodes, the edge set  $E = e_1, e_2, \dots, e_m$  consists of  $m$  two-element subsets of  $V$  — each edge being on the form  $v_i, v_j$ , but written  $v_i, v_j$  to denote the edge.

In this dissertation the problem of the decision-maker — the crime-investigator — is to assess the effect of a given set of reported observations on the certainty of given hypotheses about uncertain events, for the purpose of optimizing the outcome with respect to given statements about consequences. In terms of graph theory, the objects and relationship of interest in this decision-problem are *propositions*, or the *events* claimed by these, and their logical and causal relationships.

The logical and causal nature of this problem restricts the kind of graphs relevant to so-called *Directed Acyclic Graphs* (DAGs), where the edges are added arrowheads to signify the direction of the believed logical implication or causal influence. A DAG is thus a formal representation of the logical or causal connections between propositions identifying certain entities with specified characteristics. The only constraint of DAGs is that you may not directly represent recursive relationships — any specified sequence of connected nodes must be *acyclic*. A DAG may thus be used to model a given inference problem when the need is to estimate the certainty of hypotheses in light of evidence but where there is a risk of bias due to complex conditioning and/or — in the case of a recurring problem — changing decision-makers.

A DAG  $D$  consists of a set of a finite nonempty set of nodes  $V(D)$  together

with a set of **ordered** pairs of distinct nodes called **arcs**. When talking about the relationships in DAGs it is customary to use family relations: If there is a directed edge from  $A$  to  $B$ ,  $A$  will be called a *parent* of  $B$  and  $B$  a *child* of  $A$ . Any node may thus have *ascendants* and *descendants*. A node without ascendants will be called a *root node* and a node without descendants will be called an *end node*. An arc  $AB$  goes from  $A$  to  $B$  and  $A$  is said to be **adjacent to**  $B$  while  $B$  is said to be **adjacent from**  $A$  — to signify one-way traffic only (Buckley and Lewinter 2003: 261-265). A DAG will have certain *connectivity*-properties providing three basic reasoning rules which may be exploited when accounting for uncertainty in given complex inference problems:

An inference problem may contain events connected *serially*, where, say,  $A$  is known to affect or imply  $B$ , which in turn is known to affect or imply  $C$ .

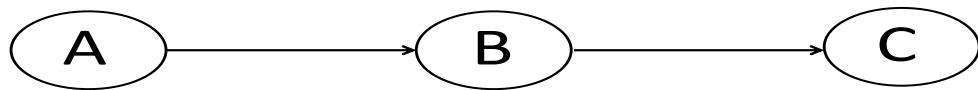


Figure 9.1: A serial connection.

If we receive evidence that  $A$  is in one of its possible states, this will change the certainty of  $B$  — which in turn will change the certainty of  $C$ . Similarly, were we to receive evidence that  $C$  is in one of its states, then this will change the certainty of  $B$  which in turn will change the certainty of  $A$ . But if we receive evidence that  $B$  is in one of its states, being *instantiated*, then any knowledge of  $A$  would not matter for the certainty of  $C$  — the

channel becomes blocked. Knowledge about  $B$  thus makes  $A$  independent of  $C$ , or, in graph-theoretical terms,  $A$  and  $C$  are *d-separated* given  $B$ .

**Proposition 9.18. (*Justification by serial connection*).**

*Justification may be transmitted through a serial connection unless the state of the event in the connection is known.*<sup>2</sup>

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<sup>2</sup>Jensen 2001:6, slightly reformulated.

A second kind of connection between events is the *diverging* kind, where  $A$  alone influences or implies two or more other events  $B, C, \dots E$ :

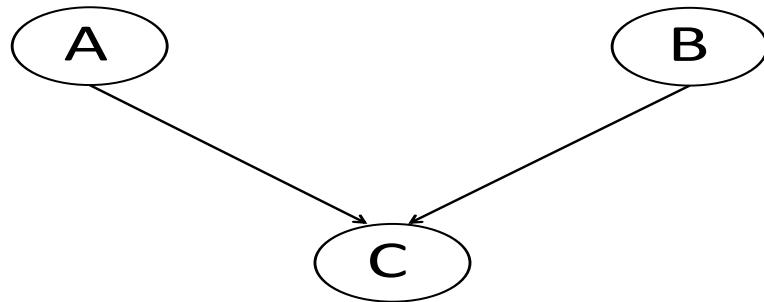


Figure 9.2: A diverging connection.

If we do not know the state of  $A$ , then influence may pass between  $A$ 's children; if  $A$  is known, then the channel between the children is blocked. In graph-theoretical terms: Evidence may be transmitted through a diverging connection unless the parent is instantiated — then the children become d-separated.

**Proposition 9.19. (*Justification by diverging connection*).**

*Justification may be transmitted through a diverging connection unless the state of the parent-node in the connection is known or evidenced.<sup>3</sup>*

The third kind of connection between variables is the *converging* kind, where one child has several parents:

If nothing is known about the child, except what is known about its parents, then the parents are d-separated. In this case, receiving knowledge

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<sup>3</sup>Jensen 2001:7, slightly reformulated.

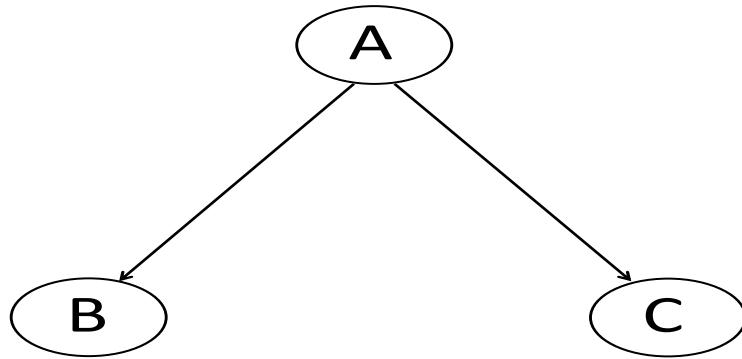


Figure 9.3: A converging connection.

about one parent does not tell you anything about the state of any of the other parents. But if you receive evidence on the state of the child from other sources than the parents, then the parents become *d-connected*: Information on the child opens up the channel between the parents; information on the child affecting the certainty of a parent also tells about the certainty about the other parents.

**Proposition 9.20. (*Justification by converging connection*).**

*Justification may only be transmitted through a converging connection if either the child-node or one of its descendants has received evidence.<sup>4</sup>*

The three rules above cover all the ways in which justification, effect, or evidence may be transmitted in a causal network. If adhering to these, the analyst is enabled to decide for any pair of nodes whether they are dependent or not given information on any of them. The following definition of d-separation will apply:

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<sup>4</sup>Jensen 2001:8, slightly reformulated.

### Definition 9.14. (**d-separation**).

Two variables [events]  $A$  and  $B$  in a causal [or logical] network are *d-separated* if for all paths between  $A$  and  $B$  there is an intermediate variable [event]  $V$  such that either

- the connection is serial or diverging and the state of  $V$  is known or
- the connection is converging and neither  $V$  nor any of its descendants have received evidence.

If  $A$  and  $B$  are not *d-separated* we call them **d-connected**. Jensen (2001: 10).

A DAG may thus model the causal impact between the events of these propositions — in a given inference problem. The statement in the model will be:

*The event  $A$  causes with certainty  $x$  the event  $B$ .*

Our reasoning is:

*If we know that  $A$  occurred, then  $B$  occurred with certainty  $x$*

This coincides with the reasoning of a crime-investigator in the later stages of an investigation of a particular case: He/she knows that the prosecutor will only bring an indictment to court if all the necessary legal conditions are provable beyond a specified probability by the evidence. The investigator must deduce the implications down to the observations of lay or expert witnesses:

*If the [indictment] is true then this implies that the [means of evidence] must be true, which in turn implies that [event<sub>1</sub>] must be true, which in turn implies that ... [event<sub>i+1</sub>] must be true.*

This deduction of implications was informally done with respect to the bitemark-theme of the Torgersen-case in the chapters 4, and 5. A DAG over this inference problem would look much like the figures at in those chapters. But this deductive explication of logical implication is of course not sufficient as it only tells the investigator that the certainty of an assumed implication-proposition depends on the certainty of its premise-proposition in a specific

way. What is needed is a way to assess how the certainty of an implication can inform about the certainty of a suggested premise given the suggested specification of a logical relationship — because the assumed implications of a main premise (which has already happened) are the only components the investigator can more directly assess the certainty of. In a DAG the inversion of the relationship between premise-node and its implication-node is done by using Bayes' Rule on the probabilistic relationship between variables representing the events hosted by the nodes. Bayes Rule was specified above as was the other consequences of probability calculus which is exploited in a DAG-representation of a decision-problem.

Using the formulation chosen by Jensen (2001) a definition of Bayesian Networks can be given:

**Definition 9.15. (Bayesian Network).**

A **Bayesian Network** consists of the following:

- A set of **variables** and a set of **directed edges** between variables.
- Each variable has a finite set of mutually exclusive states.
- The variables together with the directed edges form a **directed acyclic graph (DAG)**. (A directed graph is acyclic if there is no directed path  $A_1 \rightarrow \dots \rightarrow A_n$  s.t.  $A_1 = A_n$ .)
- To each variable  $A$  with parents  $B_1, \dots, B_n$ , there is attached the potential table  $P(A | B_1 \dots B_n)$ . (Jensen 2001:19-20)

As said in the section on inference-problems as decision-problems, the former may be said to contain a universe of events,  $U = E_1 \dots E_n$ . The degrees of belief we have in the occurrence of these events may be represented by probability. If we have access to the joint probability table  $P(U) = P(E_1, \dots, E_n)$ , we may calculate both  $P(E_i)$  as well as  $P(E_i | G)$ , where  $G$  is relevant events or observations. But as the table for  $P(U)$  grows exponentially with the number of events it will not take many before calculation becomes unmanageable. This is where the *connectivity*-properties of a DAG, expressed above in terms of the three reasoning rules, come in to assist the analyst: By exploiting the conditional independences believed/suggested to exist between the events of an inference problem, a Bayesian Network is said to offer a compact representation of  $P(U)$ , where  $P(U)$  may be calculated from the different probability-tables specified in the network:

### **Definition 9.16. (The chain rule for Bayesian Networks)**

Let  $BN$  be a Bayesian network over  $U = A_1, \dots, A_n$ . Then, the joint probability distribution  $P(U)$  is the product of all the potentials specified in  $BN$

$$P(U) = \prod_i P(A_i | pa(A_i)),$$

where  $pa(A_i)$  is the parent set of  $A_i$ . (Jensen 2001:21)

As we see, the chain rule of Bayesian Networks expresses the same as that of the definition 9.9 above, of conditional independence. The above property, called the chain rule, constitutes a fundamental property of Bayesian Networks and is in the literature referred to as the *Markov property* of an inference problem:

### **Definition 9.17. (The Markov property)**

A DAG with a joint probability distribution  $P(\cdot)$  over its variables is a Bayesian Network if and only if

- for every variable  $A$  in the DAG, and every set  $B$  of variables such that it does not include the set of descendants of  $A$ ,  $A$  is said to be conditionally independent from  $B$  given the set of parent variables of  $A$ :

$$P(A | B, pa(A)) = P(A | pa(A))$$

(Taroni et al. (2006:51)).

This ends the presentation of the graph-theoretical component of the methodology of  $\mathbf{BN}_s$ . This component is a corroborating heuristic, not epistemologically necessary for simpler problems like the one of this dissertation, but invaluable when the number of events becomes larger and/or when there is a particular need to justify the model chosen for a given problem. Together with the Bayesian Theoretical norms of coherency and the heuristics enabling quantification of degrees of beliefs and wants it makes the  $\mathbf{BN}_s$  a possible methodology or inference-procedure by which crime-investigative decisions about means of evidence can become evidence-based.

## 9.6 Conclusion

In this chapter I have presented the epistemological norms and terms of the methodology of  $\mathbf{BN}_s$ . The norms, expressed by the three axioms in section 2, are anchored in specified rules of logic — rules well agreed to serve a decision-maker needing to achieve certain consequences while avoiding certain others. Adherence to these norms and their underlying logical rules is the basic necessary requirement for the formulation of precise/unambiguous reference-groups and -terms and is therefore a fundamental normative element of the standard of evidence-basis specified in Premise 1 in the first chapter of this dissertation. The quantification of degrees of beliefs and preferences, and the provision of the numerical measures for expressing these, are *heuristics* — analytically useful instruments compatible with these norms.

In the next chapters I will use  $\mathbf{BN}_s$  to model the crime-investigative problem of deciding about the relevance of a bitemark-means with respect to a particular legal indictment.

# Chapter 10

## The crime investigator's bitemark-problem interpreted in the terms of Bayesian Theory

In this and the next two chapters I will use BN<sub>s</sub> to construct an evidence-basing decision-procedure to the crime investigator with a particular kind of bitemark-problem. In this chapter I will, first, specify a particular kind of bitemark-problem in the terms of BN<sub>s</sub>; then derive the general likelihood-ratio of such bitemark problems; and thirdly, suggest this ratio as the instrument by which the investigator may assess the basic evidential value of bitemark-means when having a bitemark-situation similar to the one modelled.

### 10.1 The bitemark-problem

Recall that I in this dissertation only attend to the problems directly relevant to the crime investigator in the investigative phase of the criminal case process — when he/she analyses and decides on the *positive* claims involved in case-specific means of evidence, aiming truth and certainty for these decisions, in terms of highest possible accuracy, unambiguity, objectivity, and impartiality. This positive analysis will be conditioned by the *general* ethical norms and legal codes specified for crime investigation and means of evidence,

but it will not be conditioned by what is *case-specifically* good and right — the crime investigator does not have to aspire that the analyses should be consensus-creating or conflict-reducing.

The decisions-maker of the bitemark-problem is thus the crime investigator. He or she is in the latter stages of the crime-investigative phase of a given crime-case: A victim, the legal injuries, and a suspect have been identified; most of the information has been detected and collected; and one or more *legal indictments* — claims about individuals, objects, actions, and relationships formulated in legal terms — have been identified. The typical problem of the investigator in this phase is to assess the various *means of evidence* — claims implied if the legal indictment is true — and determine whether these means are *positively relevant* to the indictment(s) to the degree required by law. I will attend to a particular subgroup of such decision-problems:

- The decision whether or not a suspected bitemark observed on the skin of the victim was caused by an identified suspect simultaneously with the legally relevant injuries in the case.

In the following I will specify this bitemark-problem in the formal terms of  $\text{BN}_s$ .

### 10.1.1 The context

The crime-investigator is thus only to attend to the positive aspects — the physical as well as the motivational possibilities — of the occurrence of the suspected bitemark: "If it is a human bitemark, **how**, **why**, and **when** did it occur here?" The assessment of the motivational possibilities requires information about the reasoning of the biter and presumes that the physical possibilities have already been assessed and decided on. In this dissertation I constrain to the *physical* — spatial and temporal — positive possibilities of the bitemark-means.

Bitemarks in crime cases do not occur as often as fingerprints, biological material, or other traces, but often enough to exhibit considerable variability. They may be more or less easy to classify on the standard set of markers used for the different diagnostic purposes: Both weak and severe bitemarks — made by more or less force or by severe stretching of the skin, made by mobile teeth or a damaged biting-mechanism — will make it difficult for the bitemark-experts to agree on the mark-contour of a given bitemark.

Agreeing on the basic contour is necessary for the expert-decision about the kind and number of markers necessary for the differentiation between possible biting-mechanisms. In order not to involve too many uncertainties, the decision-problem will be constrained to include only a specified subgroup of bitemarks. Other initial conditions will be fixed as well when searching for an evidence-based solution to the investigator's bitemark-means problem.

The investigator's accumulated knowledge and experience of similar and different problems and his/her general or case-specific formal or informal obligations; the assumptions specified in the first chapter of this dissertation; and the following set of initial conditions will constitute the *context* of the decision-maker and his/her problem:

- There is a crime investigator in charge of the investigation of a crime case and who is at the moment investigating the probable truth of the following *indictment-proposition*:

"The identified suspect  $S = s$  is the causal agent of the crime act  $CA = ca$  which caused the legally relevant injuries  $LI = li$  to the victim  $V = v$  and which occurred at time  $T = t_0$  and place  $PL = pl_0$ ."

This *indictment-proposition* is less complex than the proposition which will be referred to as the *legal indictment*: The former is a causally/logically necessary consequence of the latter and is simpler in that it does not include the legal terms necessary for the ultimate decision at the end of the trial phase — the former only includes the a-legal terms necessary for the crime investigative decision at the end of the investigative phase about the causal mechanism behind the event under investigation.

- The investigator is fully informed about the basic non-negotiable aims associated with crime investigative decisions: He/she must (a) contribute to convict the guilty or acquit the innocent and must **not** contribute to convict the innocent or acquit the guilty; and (b) contribute to secure the resources available to other cases and **not** contribute to undermine such resources;
- The crime investigator is formally required to provide *evidence-based* decisions about *any* suspected means of evidence: He/she must explicitly, in a written format, justify, in terms of the reference-groups and -terms, how and why (a) the means is positively or not positively relevant and (b) the risk of being wrong about (a) is sufficiently small. The crime investigator knows that this report is itself a means of evidence with respect to the claim that the investigation did not undermine any of the aims and values involved in the criminal case process.
- In addition to the legally relevant injuries ( $li$ ) identified in the proposition above, there is a given set of observations of other possible effects of the causal mechanism behind the event which occurred in the specified  $T = t_0$  and  $PL = pl_0$ . Among

these observations are two sets of *skinmarks* on the person legally injured: (1) There is a skinmark *known* to be a direct effect of the crime act — from now on *li* denotes only this skinmark; and (2) there is a skinmark *suspected* to be an effect of acts related to the crime act — this skinmark will be denoted by  $CM = cm$  (Crime Mark of unknown cause). Both these skinmarks will be assumed to be truly externally caused skin-injuries;

- The crime mark,  $cm$ , belongs to the following subgroup of skinmarks:
  1. on the skin of a living or a deceased human being;
  2. is classified as 3 or 4 (high forensic significance) on Pretty's *Bitemark Severity and Significance Scale* (Pretty 2007);
  3. has no transferred components (no unknown cell-material, fibre, etc.);
- The crime investigator has already decided (evidence-based) that there were only two human causal agents present at  $t_0$  and  $pl_0$ . In the following I will assume that this decision is without uncertainty of any kind: The problem is thus assumed to be a true *one-offender* problem.
- The crime investigator is at the moment investigating the relevance of the following proposition with respect to the indictment-proposition above:

"The suspect  $S = s$  is the causal agent of  $cm$  which is a bitemark  $CBM = cbm$  which occurred at time  $T = t_0$  and place  $PL = pl_0$ ."

This *bitemark-proposition* is less complex than the proposition of the *bitemark-means*: The former is a causally/logically necessary consequence of the latter and is simpler in that it does not include the legal terms necessary for the ultimate decision at the end of the trial phase.

- The crime-investigator needs to assess two questions in order to decide about the relevance between the bitemark-proposition and the indictment-proposition
  1. Is  $s$  the cause of  $cm$ ?
  2. Was  $cm$  made simultaneously with  $li$ ?
- The crime investigator needs to request diagnostic assistance from a trained and experienced forensic bitemark-expert with respect to the following questions:
  1. "Is  $cm$  a human bitemark ( $CBM = cbm$ )?"
  2. "If  $cm$  is a human bitemark, is it caused by  $s$ ' biting-mechanism  $SBM = sbm$ ?"
  3. "If  $cm$  is a human bitemark, was  $cbm$  caused simultaneously with  $li$ ?"
- the crime-investigator is responsible that any diagnostic decisions made by any expert is evidence-based: He/she must ensure that the experts explicitly, in a written format, justify, in terms of the reference-groups and -terms, why and how each of these diagnostic decisions is positively relevant or not positively relevant (to the

investigator's bitemark-proposition) and why and how the risk of being wrong is sufficiently small. The crime investigator is responsible that the expert knows that the expert-report is itself a means of evidence with respect to the claim that the expert-analyses did not undermine any of the aims and values involved in the criminal case process.

- The objects observed by any expert or investigator exist and are authentic (the chain of custody will be assumed to be perfectly intact, without uncertainty);
- The crime investigation of the bitemark-proposition, including the expert-analyses, has been performed according to the ethical norms and legal codes/rules/instructions generally conditioning crime investigation and forensic analyses.
- The experts and the investigators are normally truthful and have normally working senses and reasoning-faculties (logical, cognitive, and emotional).

This particularly conditioned situation, or *context*, will be denoted by  $K_0$ . Any conclusions arrived at in the remaining sections and chapters of this dissertation are relevant only for situations representative of the above situation.

### **10.1.2 The relevant *decision-options* of the problem**

In general, the outcomes of a bitemark-problem are as follows: Either the bitemark-proposition is strictly positively relevant; it is strictly negatively relevant; or it is not relevant to the indictment-proposition. "Strictly positively relevant" can be concluded when the expert-information is sufficiently discriminatory and sufficiently more probable under the bitemark-proposition than under its negation; "strictly negatively relevant" can be concluded when the expert-information is sufficiently discriminatory and sufficiently more probable under the negation of the bitemark-proposition than under the bitemark-proposition; and "not relevant" can be concluded when the expert-information is not sufficiently discriminatory or not more probable under the bitemark-proposition than under its negation. Under the  $K_0$  specified above the possible outcomes will be set to be "strictly positively relevant" and "not strictly positively relevant". There are several ways in which a bitemark-proposition may be "not strictly positively relevant", with separate effects on the evidential role of the bitemark in the investigation. I will return to this later. Now I will just identify the two possible options of the crime-investigator of my decision-problem:

$a_i$  ,  $i = \{1, 0\}$ ;

$a_1$  denotes the option of deciding that the bitemark-proposition is strictly positively relevant to the indictment-proposition, and

$a_0$  denotes the option of deciding that the bitemark-proposition is not strictly positively relevant to the indictment-proposition.

### 10.1.3 The relevant events of the problem

I have already specified the events of bitemark-proposition and the indictment-proposition in the list containing the initial conditions of the analysis. There I also hinted at three logically and immediately necessary consequences of the bitemark-proposition in the form of questions. In the historical case discussed in chapter six I elicited the further consequences of these propositions/questions. In the following I will keep the denotations for these, but collapse some and abstract the particular identities of that case. The basic relevant propositions and their events is listed below:<sup>1</sup>

*PC:* "The identified suspect,  $s$ , is the causal agent of the crime act which caused the legally relevant injuries to the victim and which occurred at time  $T = t_0$  and place  $PL = pl_0$ .";

*BM:* " $s$ , via his/her biting-mechanism  $SBM = sbm$ , is the causal agent of this bitemark (Crime Bite Mark,  $CBM = cbm$ ) which occurred at time  $T = t_0$  and place  $PL = pl_0$ ."

*BM1:* " $sbm$  is the causal object of  $cbm$ ";

*BM1.1:* " $sbm$  is observed to have the profile  $bmi1_{sbm}$  with respect to  $BMI1$  (the bitemark-index relevant for biting-mechanisms when the bitemark belongs to the subgroup specified).";

*BM1.2:* " $cbm$  is observed to have profile  $bmi2_{cbm}$  with respect to  $BMI2$  (the bitemark-index relevant for suspected bitemarks on human skin and belonging to the subgroup specified).";

*BM2:* " $cbm$  was caused simultaneously with  $li$ ";

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<sup>1</sup>Appendix 4 contains a detachable list to ease the reading.

*BM2.1: "li is observed to have the profile  $ti_{li}$  with respect to  $TI$  (the time-index used for determining the stage of the repair process of skin-injuries.);*

*BM2.2: "cbm is observed to have the profile  $ti_{cbm}$  with respect to  $TI$ ) (the time-index used for determining the stage of the repair process of skin-injuries).".*

I have presented these propositions as *claims*, which may be true or false. It would perhaps have been more appropriate to let the propositions be *questions* — to stress the *epistemological* principle that the events in question are not directly accessible to us. On the other hand it would perhaps be more appropriate to address the *events* of the propositions directly and not mix in the associations connected to propositions expressed in a natural language — to stress the *methodological* principle of precision and simplicity. Whether the "objects" of the decision-problem are propositions, questions, or events does not matter much methodologically (I hold) and I shall sometimes speak of propositions (questions), sometimes of the events they are about.

#### **10.1.4 The relevant *consequences* of the problem**

So far I have identified the possible options and the relevant events of the bitemark-problem. Under the specification of  $K_0$  I also identified the aims of the decision: (a) to contribute to convict the guilty person or to acquit the innocent person and to *not* contribute to convict the innocent person or to acquit the guilty person and (b) to contribute to protect resources intended for other case and *not* contribute to lessen such resources. As we do not know whether the events really occurred or not, the crime-investigator and/or the expert's choice of decision-option may be either correct or wrong: In the case the decision are correct, then the aims will be achieved as intended; In the case the decision is wrong, then the aims will not be achieved. The possible consequences when the investigator wants to choose/decide  $a_1$  ("The bitemark-proposition is strictly positively relevant") are: (1) The decision is correct and the investigator contributes to convict the true guilty; and (2) the decision is wrong and the investigator contributes to convict a true innocent. The possible consequences when the investigator wants to decide  $a_0$  ("the bitemark-proposition is not strictly positively relevant") are: (1) The decision is correct and the investigator contributes acquit a true innocent; and (2) the

decision is wrong and the investigator contributes to acquit a true guilty. I will suggest the following order for these specified possible consequences:

- c<sub>1</sub>*: Decide "strictly positively relevant" correctly and contribute to convict a true guilty;
- c<sub>2</sub>*: Decide "not strictly positively relevant" correctly and contribute to acquit a true innocent;
- c<sub>3</sub>*: Decide "not strictly positively relevant" wrongly and contribute to acquit a true guilty;
- c<sub>4</sub>*: Decide "strictly positively relevant" wrongly and contribute to convict a true innocent;

I believe it to be justified to accredit the first consequence as an absolute best and the last as an absolute worst: This and the suggested ordering are compatible with practical outcomes and compatible with the general value structure expressed by the legal principles of "innocent until proven guilty" and "it is better to acquit ten guilty than to convict one innocent".

A decision of positive or not positive relevance may also have consequences on the resources — in terms of money, time, and expertise (crime investigative as well as forensic/scientific) — allocated to crime investigations of cases similar to the one in question. To use more than the allocated share of resources in one case means less resources to the next case — which may possibly contribute to increase the risk of incorrect decisions in that case. Indeed, a substantial part of the justification for requiring evidence-based public decisions is via the limited resources of the modern welfare state. The question whether resource-costs are justifiable will depend on both legal-general and case-particular conditions: The legal kind of crime act under adjudication; the case-specific circumstances of that act; the expected symbolic value of the legal decision in the particular case; the accuracy expected of particular means of evidence in question; and the relative evidential burden hosted by given means of evidence.

In cases like the Torgersen-case from Part II a host of circumstances would generally justify resource-costs. In that case the resources invested in the bitemark-means were considerable and there is no question that the resources available to other cases thus were reduced. But in light of the current

generally weak discriminatory power of bitemark-diagnosis, compared to say fingerprint- or genetic profiling means, I suggest that a bitemark-means can only justify costs if the bitemark is of the subgroup specified above and if the bitemark-means are *corroborated* by other means of evidence — i.e. if it is not strictly necessary for or against the indictment but assists means of evidence more accurately able to increase or decrease the certainty of the indictment

Due to this I will have to specify one further initial condition for the crime investigator's decision-situation:

- The bitemark-means of evidence suspected relevant to the indictment assessed is not a necessary means of evidence, only a *corroborating* means of evidence — only applicable for increasing or decreasing an already sufficient degree of certainty of the truth or the falsity of the indictment.

To simplify the consequence-possibilities while awaiting more accurate bitemark-analysis I will simply assume that the above four possible legal-specific consequences are the relevant consequences.

### 10.1.5 Representing by probability and utility

So far I have specified the basic components of the investigator's bitemark-problem. But to proceed with the problem within the BN<sub>s</sub> I must first assume that the class of events claimed by the propositions above has the structure of an algebra. Holding the axioms, propositions, and the definitions from the previous chapter we may first express the uncertainty about the occurrence of the events of the propositions in the standard of probability, as probability-functions. Letting  $\sim$  denote "represented by",

$PC \sim PC_j, j = \{p, d\};$  Degree of belief in  $PC_j \sim P(PC_j),$   
 $P(PC_j) = (p_{PC_p}, p_{PC_d});$   $p_{PC_j} > 0;$   $(p_{PC_p} + p_{PC_d}) = 1.$   
 $PC_p$  denoting that the event occurred and  $PC_d$  denoting that the event did not occur, to be claimed by the prosecution and the defence counsel respectively.

$BM \sim BM_j, j = \{1, 0\};$  Degree of belief in  $BM_j \sim P(BM_j),$   
 $P(BM_j) = (p_{BM_1}, p_{BM_0});$   $p_{BM_j} > 0;$   $(p_{BM_1} + p_{BM_0}) = 1.$   
 $BM_1$  denoting that the event occurred and  $BM_0$  denoting that the event did not occur, to be claimed by the prosecution and the defence counsel respectively.

$BM1 \sim BM1_j, j = \{1, 0\}$ ; Degree of belief in  $BM1_j \sim P(BM1_j)$ ,

$$P(BM1_j) = (p_{BM1_1}, p_{BM1_0}); \quad p_{BM1_j} > 0; \quad (p_{BM1_1} + p_{BM1_0}) = 1.$$

$BM1_1$  denoting that the event occurred and  $BM1_0$  denoting that the event did not occur, to be claimed by the prosecution and the defence counsel respectively.

$BM1.1 \sim bmi1_{sbm}, \{bmi1_{sbm}, \neg bmi1_{sbm}\}$ ; Degree of belief in  $bmi1_{sbm} \sim P(bmi1_{sbm})$ ,

$$P(bmi1_{sbm}) = (p_{bmi1_{sbm}}, p_{\neg bmi1_{sbm}}); \quad p_{bmi1_{sbm}} > 0; \quad (p_{bmi1_{sbm}} + p_{\neg bmi1_{sbm}}) = 1.$$

$bmi1_{sbm}$  denoting the event that the suspect's biting-mechanism has profile  $bmi1$  and  $\neg bmi1_{sbm}$  denoting the event that the suspect's biting-mechanism has a different profile than  $bmi1$  — on the  $BMI1$ -index relevant for biting-mechanisms in the specified bitemark-situation

$BM1.2 \sim bmi2_{cbm}, \{bmi2_{cbm}, \neg bmi2_{cbm}\}$ ; Degree of belief in  $bmi2_{cbm} \sim P(bmi2_{cbm})$ ,

$$P(bmi2_{cbm}) = (p_{bmi2_{cbm}}, p_{\neg bmi2_{cbm}}); \quad p_{bmi2_{cbm}} > 0; \quad (p_{bmi2_{cbm}} + p_{\neg bmi2_{cbm}}) = 1.$$

$bmi2_{cbm}$  denoting the event that the bitemark has profile  $bmi2$  and  $\neg bmi2_{cbm}$  denoting the event that the bitemark has a different profile than  $bmi2$  — on the  $BMI2$ -index relevant for bitemarks of the specified bitemark-situation

$BM2.1 \sim ti_{cbm}, \{ti_{cbm}, \neg ti_{cbm}\}$ ; Degree of belief in  $ti_{cbm} \sim P(ti_{cbm})$ ,

$$P(ti_{cbm}) = (p_{ti_{cbm}}, p_{\neg ti_{cbm}}); \quad p_{ti_{cbm}} > 0; \quad (p_{ti_{cbm}} + p_{\neg ti_{cbm}}) = 1.$$

$ti_{cbm}$  denoting the event that the bitemark has profile  $ti$  and  $\neg ti_{cbm}$  denoting the event that the bitemark has different profile than  $ti$  — on the  $TI$ -index relevant for estimating the age of skinmarks in the specified bitemark-situation

$BM2.2 \sim tili, \{tili, \neg tili\}$ ; Degree of belief in  $tili \sim P(tili)$ ,

$$P(tili) = (p_{tili}, p_{\neg tili}); \quad p_{tili} > 0; \quad (p_{tili} + p_{\neg tili}) = 1.$$

$tili$  denoting the event that the control-injury known to be an effect of the legal injury has profile  $ti$  and  $\neg tili$  denoting the event that the control injury has different profile than  $ti$  — on the  $TI$ -index relevant for estimating the age of skinmarks in the specified bitemark-situation

and then, secondly we may express the preference among the consequence-propositions in the standard of utility, as a utility-function:

$(c_1 \text{ through } c_4) \sim c_k, k = \{1, 2, 3, 4\}$ ; Value associated with  $c_k \sim U(c_k)$ ,

$$U(c_k) = (u_{c_1}, u_{c_2}, u_{c_3}, u_{c_4}).$$

$c_1$  denoting the extreme consequence of having contributed to convict the true guilty, the absolutely best;

$c_2$  denoting the consequence of having contributed to acquit the true innocent, the next most valued;

$c_3$  denoting the consequence of having contributed to acquit the true guilty, the next least valued; and

$c_4$  denoting an extreme consequence, of having contributed to convict the true innocent, the absolute worst.

Having thus a bounded decision-problem for the crime-investigator's bitemark-problem in the form of probability functions for the relevant events and a utility function for the relevant consequences, it remains to specify the general measure of the value attached to the possible actions or decisions,  $a_i$ , that the investigator can make. As said, the investigator will be seen to have two possible decisions: Either decide that the  $BM_j$  is strictly positively relevant or decide that it is not strictly positively relevant:

$$a_i, i = \{1, 0\};$$

$a_1$  denoting the option of deciding that  $BM_j$  is strictly positively relevant to  $PC_j$ , and  $a_0$  denoting the option of deciding that  $BM_j$  is not strictly positively relevant to  $PC_j$ .

The form of this value depends on both the events specified to constitute the certain event  $\Omega$  and on the particular consequences to which these events lead. The conditional expected utility of the crime investigator's decision about the relevance of the bitemark-proposition with respect to the indictment-proposition will be expressed by

$$\bar{u}(a_i | c_k, BM_j) = \sum u(a_i(c_k)) P(BM_j)$$

A decision-criterion for the crime investigator in this situation follows from the assumptions, definitions, and propositions given in the previous chapter:

*For this bounded decision with extreme consequences  $c_4 < c_3 < c_2 < c_1$  and  $BM_j > \emptyset$ ,*

$$a_1 \leq_{BM_j} a_0 \leftrightarrow \bar{u}(a_1 | c_k, BM_j) \leq \bar{u}(a_0 | c_k, BM_j).$$

A best decision will exist as the set of options considered in this practical decision problem is finite. This criterion recommends that the crime investigator should decide that  $BM_j$  is not strictly positively relevant to  $CP_j$  if it is found that the expected utility of deciding that it is strictly positively relevant is equal or less than the expected utility of deciding that it is not so.

The above specified, ordered, and finite collection of the relevant events, relevant consequences, relevant decision-options, their respective measure-heuristics, and the decision-criterion or norm are then the basic components of the crime investigator's decision-problem in the above specified situation  $K_0$ .

### **The specification of the embedded expert-problem**

The decision about the relevance of the bitemark-proposition is made by the crime-investigator, but he/she cannot decide about this before the experts have analyzed and concluded about the two bitemark-criteria —  $BM1_j$ , whether the suspect's biting-mechanism is the cause of the bitemark, and  $BM2_j$ , whether the bitemark occurred simultaneously with the control-injury. As I have specified the situation, the expert-conclusions must be evidence-based as well, i.e. provide information about the risk of wrong decisions. It is the crime investigator who needs to ensure that he/she gets that kind of information from the experts.

The components of these *embedded* decision-problems of the experts are not different in kind from the crime investigator's problem. The events claimed by  $BM1$  and  $BM2$  have already been specified and represented as events being uncertain according to the general structure of probability — as have the events presumed by them ( $bmi1_{sbm}$ ,  $bmi2_{cbm}$ ,  $ti_{cbm}$ , and  $ti_{li}$ ).

It would have been desirable to specify further the subcomponents of these two diagnostic problems. The bitemark was above assumed to be forensically significant in the sense of being classified as 3 or 4 (high forensic significance) on Pretty's *Bitemark Severity and Significance Scale* (Pretty 2007). This criterion was set to ensure a minimum level of expert consensus about the basic diagnosis about the causal object of the skinmark, but also about the orientation of the upper vs. the lower jaw's marks as well as the specification of the kind of teeth involved, whether marks are from molar, canine, or incisor kinds of teeth. The further differential diagnoses require observations of  $BMI1$ ,  $BMI2$  and  $TI$  — the profiling-instruments relevant in given situations.

In the Torgersen-case from Part II of this dissertation we saw that the experts for example chose to observe *kind and degree of wear and degree of regularity among the individual marks and teeth relative to the arch-line*. Other characteristics were observed as well, some not explicitly specified. But any given bitemark will require and be subject to different and subjectively composed and thus particular profiling instruments. This is different from

forensic genetics where the expert has access to a delimited set of characteristics or markers, which are agreed on, well specified, and well studied in different populations. In bitemark-analysis, even though the experts seem (in the literature) to agree that, say, rotation and position of teeth and marks are relevant characteristics, they have not agreed on one standard definition and method of observation: each expert has his/her own preferred definitions — some preferring precise definitions, others prefer more inclusive terms — and each has his/her own techniques for observation — some preferring to observe unaided, some prefer microscopes, some prefer stereoscopes, and some prefer computer-software (which they do not agree on either). A few studies exist concerning the distribution of given characteristics, but these concerns biting-mechanisms only or bitemarks in flat dental wax without mentionable visco-elasticity. But when the definition and observation used in that study cannot be expected used by the next expert, the study becomes rather worthless. There is unfortunately very little which may be safely assumed concerning the relationship between a characteristic observed of biting-mechanisms and the corresponding characteristic observed of the bitemarks from those mechanisms or the relationship between different characteristics observed of biting-mechanisms or bitemarks.

In the next chapter I venture certain distributions and relationships, but that will only be for illustrating the methodology and the model suggested in this chapter. Awaiting better knowledge about the constituent characteristics and relationships I will abstain from differentiating the profiling instruments *BMI2*, *BMI1*, and *TI* any further.

However crude the specification of the profiling-instruments, it is still possible to specify the consequences of the expert-decisions. These are in principle similar to those commonly used in the scientific context — to avoid error of type I (of rejecting the null hypothesis when it is true) and II (of not rejecting the null hypothesis when it is false), but the practical aims are similar to those of the crime investigator and can be expressed in the terms of Bayesian Theory: To reduce as much as possible the risk of deciding wrongly about a given question by choosing the decision which maximizes the expected utility.

This ends the specification of the components involved in the delimited crime-investigative bitemark-problem.

We may now proceed to simplify or standardise the solution of the decision-

problem: We may exploit (a) the logical rules made possible by above specification of the relevant events and (b) the heuristic of graph-theory in order to establish an agreement about the best logical and causal relationships existing among the events involved.

## 10.2 Using the likelihood ratio to express the value of the expert-information

The basic problem of the crime investigator is thus to determine whether the expert-observations are more probable if the bitemark-proposition were to be true than if its negation were to be true. One standard way in methodology to assess the effect of a given set of information on a suspected hypothesis is to relate its likelihood to that of the alternative hypothesis via the *likelihood-ratio*. This will be suggested to the crime investigator with a bitemark-problem as well.

In this and the next section I will presume the scenario in which the investigator has received expert-reports on the *BMI1*-, *BMI2*-, and *TI*-profiles of the forensic items. It will be assumed that these reports are true positives:

1. It is reported that the suspect's biting-mechanism has profile  $bmi1_{sbm}$  on the *BMI1*-index; the bitemark has profile  $bmi2_{cbm}$  on the *BMI2*-index; and that the two profiles are compatible in the sense that the biting-mechanism is a possible cause of the bitemark.
2. It is reported that the bitemark has profile  $ti_{cbm}$  on the *TI*-index; the control-injury has profile  $ti_{li}$  on the *TI*-index; and that the two profiles are compatible in the sense that the bitemark-injury could have possibly occurred simultaneously with the control-injury.

In terms of Bayesian Theory the problem about the effect of the expert-information on the bitemark-proposition can be solved via Bayes Rule:

$$\begin{aligned}
 P(BM_1 \mid bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li}, K_0) = \\
 \frac{P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} \mid BM_1, K_0) \times P(BM_1 \mid K_0)}{P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} \mid BM_1, K_0) \times P(BM_1 \mid K_0)} \\
 + P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} \mid BM_0, K_0) \times P(BM_0 \mid K_0)
 \end{aligned} \tag{10.1}$$

To de-clutter the expressions I will suspend  $K_0$  ( $PC_j$  is subsumed into  $K_0$ ) from the expressions:

$$\begin{aligned} P(BM_1 | bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li}) = \\ \frac{P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} | BM_1) \times P(BM_1)}{P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} | BM_1) \times P(BM_1)} \\ + P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} | BM_0) \times P(BM_0) \end{aligned} \quad (10.2)$$

The term on the left side of the equation is the posterior probability of the hypothesis *conditional* of the expert-observations; the first term in the numerator on the right side is the *likelihood* of the hypothesis given the expert-observations; the second term in the numerator is the *prior* probability of the hypothesis; and the denominator is the *predictive* probability of the evidence.

In their *Bayesian networks and Probabilistic Inference in Forensic Science* (2006: 70-72) Taroni et al. suggest using the likelihood-ratio resulting from the odds form of Bayes' Theorem as an indication of the value of the forensic evidence. Using the basic rules of logic and probability the investigator's problem is one of comparing the likelihoods of the suspected hypothesis and its negation:

$$\begin{aligned} \frac{P(BM_1 | bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li})}{P(BM_0 | bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li})} = \\ \frac{P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} | BM_1)}{P(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} | BM_0)} \times \frac{P(BM_1)}{P(BM_0)} \end{aligned} \quad (10.3)$$

It is the first term on the right side of the equation which is the *likelihood-ratio*, sometimes called *Bayes' factor*, which can be interpreted as the effect of the observations on the hypotheses — or the ability of the evidence to change the certainty of the hypotheses (the term on the left side is the *posterior odds* on the hypothesis conditional on the evidence and the second term on the right side is the *prior odds* on the hypothesis).

Two probabilities are thus to be assessed by the investigator: First the probability of the profiles if the suspected hypothesis were to be true and

then probability of the observed profiles if the negation of this hypothesis were to be true. These two probabilities may be equal — providing a ratio of 1 — or not — providing a ratio larger than 1 or smaller than 1. If the ratio is 1 it means that the observations are not able to discriminate between the two alternative hypotheses; if the ratio is larger than 1 this indicates that the observations favour the suspected hypothesis; and if the ratio is less than 1, then this indicates that the observations favour the negation of the suspected hypothesis.

In the Torgersen-case from Part II, the Board of Forensic Medicine asked the experts about the content and their assessment of their reference-group — their  $BM_0$  and  $(bmi1_{sbm}, bmi2_{cbm}, ti_{cbm}, ti_{li} \mid BM_0)$ . The experts argued that bitemark-analysis did not and could not have this reference-basis because precise numerical observations could not be had and thus no pool of data existed for statistical techniques. This is an unhappy confusion of methodology with techniques and a failure to grasp the purpose of the former.

Indeed, statistical techniques use data in numerical form. But however mathematically sophisticated, such techniques rest on the epistemological norm, by nature qualitative, that a judgement that a phenomenon has a characteristic to a large, medium, or small degree cannot be meaningful unless compared/related to something — a standard or a reference-basis. In Premise 2 and Premise 3 of this dissertation (Chapter 1) I argue that this reference-basis is cognitively necessary as nothing can be large or larger on its own, but refers to something else being larger or smaller. If the judgement does not matter much to us we may omit this reference. Or if it for some reason is important that the judgment is not questioned too hard, we may suppress or under-communicate it. The latter may be necessary during the trial-phase's negations towards a resolution of conflicting interests. But it works only if the judgement *has been* related, and intentionally so, to a specific reference.

None of the bitemark-experts in the Torgersen-case had any qualms concluding it to be very likely (or unlikely) that the suspect's biting-mechanism was the cause of the bitemark. Judging so, they appealed implicitly to some reference-group being a relatively less (more) likely cause. But this group they had qualms talking about. The results of the study in chapter seven suggest, unfortunately, that bitemark-analysts are somehow incapacitated from making use of the ordinarily available methodological trust-generating instruments used by other scientists. This failure to adapt methodologically is, I hold, the reason why the traditional forensic sciences are under

siege (Pyrek (2007), Saks and Koehler (2005)) and is why the Norwegian Torgersen-case will not resolve peacefully.

When I as well as others suggest using the likelihood-ratio to express the evidential value of observations (expressed in numbers or words), then we merely suggest a traditional technique which is founded in traditional methodology which, in turn, is intentionally constructed to ensure adherence to basic epistemological norms — norms developed from the basic need to avoid undermining our own intentions, aims and values.

I thus suggest that the crime investigator in the situation I have specified should use the likelihood ratio as an expression of the evidential value, denoted by  $V$ , of the bitemark with respect to the indictment:

$$V = \frac{P(bmi1_{sbm}, bmi2_{cbm}, t_{cbm}, t_{li} | BM_1)}{P(bmi1_{sbm}, bmi_{cbm}, t_{cbm}, t_{li} | BM_0)} \quad (10.4)$$

Now I will turn the attention to the internal relationships between the variables involved in this likelihood-ratio. The crime investigator's bitemark-problem as it is specified is not among the most complex in terms of the number of variables involved, but I will nevertheless exploit the instrument of graph-theory to explicate the reasoning behind the suggested simplified likelihood-ratio which will be suggested at the end of this chapter. The purpose is again to explicate my justification for this simplified ratio in terms of my beliefs about the logical and causal relationships between the events claimed by the propositions identified as relevant — because this may be the reference basis from which to reconstruct the model in the case I am wrong and because it may be used as the reference-basis for any individual case-decision in the case I am correct.

### 10.3 A Directed Acyclic Graph over the crime investigator's bitemark-problem

As said in the previous chapter, a BN<sub>s</sub> over a decision-problem consists of a set of nodes hosting variables representing the relevant events of the decision-problem and a set of directed edges representing the *probabilistic dependency-relationships* between these variables; each variable may have a finite set of mutually exclusive states; the nodes and the directed edges forms

a *directed acyclic graph* — a DAG; and to each variable  $A$  with parents  $B_1, \dots, BN_n$ , there is attached the probability table  $P(A | B_1, \dots, B_n)$ .

The DAG-instrument serves two purposes: One is to model the logical and the causal relationships believed to exist among a given set of events; the other is, on the basis of the model, to simplify the calculations involved in the problem. For our bitemark-problem we may exploit categorical or logical and causal semantics and the reasoning rules of DAGs to model the problem and then use this model to elicit the subgroups of variables being conditionally independent — thus simplifying the calculation involved in specifying the decision-function for the crime investigator's problem.

The basic problem of the crime investigator is to decide the probability-distribution for  $BM_j$  conditional on the probability distributions of  $BM1_j$  and  $BM2_j$  — as these in turn are conditional on the experts' observations about the profiles of the bitemark, the suspect's biting-mechanism, and the control skin-injury.

It should be easy to agree that  $BM_j$  should be the hosted by the *root-node* of the bitemark-DAG and that  $bmi1_{sbm}$ ,  $bmi2_{cbm}$ ,  $ti_{cbm}$ , and  $ti_{li}$  should be hosted by *end-nodes* of the bitemark-DAG. The remaining nodes will host the remaining variables  $BM1_j$  and  $BM2_j$ .

In our scenario the crime investigator has received expert-reports that (1) the two profiles of  $bmi1_{sbm}$  and  $bmi2_{cbm}$  are compatible and (2) so are  $ti_{cbm}$  and  $ti_{li}$ . These profiles are observable and I have assumed the reports to be true positives.

Under the current methodological regime of bitemark-analysts it is likely that a bitemark-expert having observed such compatible profiles would then recommend to the investigator that the hypotheses of  $BM1$  and  $BM2$  were likely to be true. Under the  $BN_s$ -approach we would not be allowed to say anything about these hypotheses until we knew more about the probability of observing compatible profiles if the suspect's biting-mechanism were not the cause of the bitemark and if the bitemark were made at time different from that of the control-injury: In principle and in practice the bitemark may have been made by another person's biting-mechanisms and/or the bitemark may have been caused at an occasion irrelevant to the legally relevant injuries.

In the scenario suspected, the identified suspect is truly the biter and the bitemark was made at the time specified: Then the suspect's biting-mechanism is the true causal object of the bitemark and the bitemark did occur simultaneously with the control-injury. This scenario may be modelled as in figure 10.1.

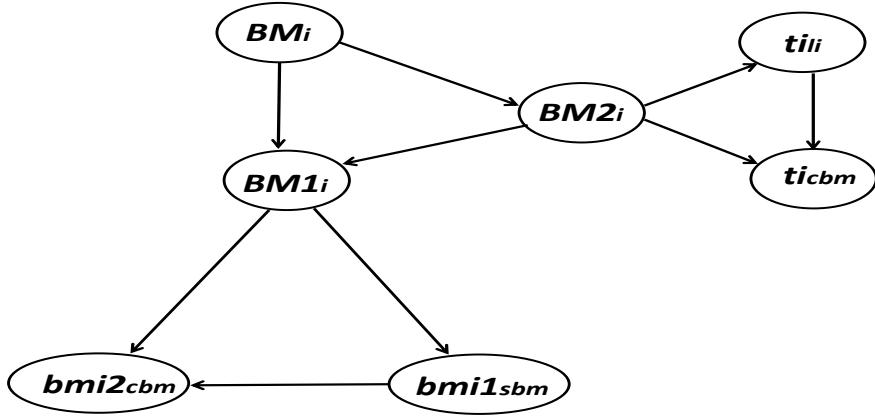


Figure 10.1: An initial bitemark-DAG: If the suspected scenario is true — that the suspect is the biter and the bitemark was made simultaneously with the control-injury — then the bitemark connects the suspect to the place and time of the legally relevant injuries; the bitemark-proposition is evidence favouring the indictment-proposition.

The question is whether some of the arrows included in figure 10.1 can be justifiably removed via rules of logic and the principles of d-separation — the aim being to arrive at subgroups of variables with more manageable contingency tables.

In the following I will rely on Cook et al. (1998)'s conceptualization of the investigative processing of forensic information: I will start at the *source-level* — on which the physical items are observed and categorized by the bitemark-experts; then I include the *activity-level* — on which the profiles observed are compared and assessed, by the bitemark-expert and the investigator in tandem, in relation to carefully chosen reference-populations; and finally I include the *crime-level* — on which the value of the aggregated information is assessed by the crime-investigator for the final decisions whether the bitemark-proposition is strictly positively relevant to the indictment-proposition.

### 10.3.1 The source-level of the problem: Classifying the bitemark, the suspect's biting-mechanism, and the control-injury

At the source-level the expert is to diagnose the suspected bitemark with respect to (1) whether it is a human adult bitemark; (2) whether the suspect's biting-mechanism is a possible cause; and (3) whether the bitemark occurred within the time-interval specified.

The first diagnosis is a sequential diagnosis: I have already assumed that the skinmark has an external and abrupt cause; a next diagnosis is whether it is a bitemark by human/animal teeth or by object with teeth-like forms; then follows the diagnosis whether it is human or animal biting-mechanism, etc. Several decisions must thus be made before considering whether some particular human biting-mechanism may be the cause. From now on I will assume the diagnosis of the bitemark as a human adult biting-mechanism as a true positive.

#### Diagnosing the bitemark's most likely causal biting-mechanism

The bitemark was caused by a human biting-mechanism and the suspect's biting-mechanism has a profile compatible with that of the bitemark. Then we have two possibilities: Either the bitemark was made by the suspect's biting-mechanism or it was made by someone else's biting-mechanism. These two possibilities were above denoted by  $BM1_1$  and  $BM1_0$  respectively:

$BM1_1$ : "s's biting-mechanism is the causal object of the bitemark";

$BM1_0$ : "Someone else's biting-mechanism is the causal object of the bitemark".

Recall the likelihood-ratio, but consider first the relationship between the profiles and  $BM1_j$ :

$$V = \frac{P(bmi2_{cbm}, bmi1_{sbm} \mid BM1_1)}{P(bmi2_{cbm}, bmi1_{sbm} \mid BM1_0)}.$$

By the third law of probability this may be expressed as

$$V = \frac{P(bmi2_{cbm} \mid bmi1_{sbm}, BM1_1)}{P(bmi2_{cbm} \mid bmi1_{sbm}, BM1_0)} \frac{P(bmi1_{sbm} \mid BM1_1)}{P(bmi1_{sbm} \mid BM1_0)}.$$

What is the nature of the relationship expressed in the second term on the right side of the equation —  $P(bmi1_{sbm} | BM1_1)/P(bmi1_{sbm} | BM1_0)$ ? Whether the suspect is the biter or not cannot change the profile of the suspect's biting-mechanism:  $P(bmi1_{sbm} | BM1_1) = P(bmi1_{sbm} | BM1_0)$ ;

$$V = \frac{P(bmi2_{cbm} | bmi1_{sbm}, BM1_1)}{P(bmi2_{cbm} | bmi1_{sbm}, BM1_0)}.$$

The numerator of the remaining term on the right side states that the probability of observing the profile of the bitemark is conditional on the suspect's biting-profile when he/she is also the biter. It is possible to agree that this event cannot be further simplified.

The denominator of the remaining term on the right side states that the probability of observing the profile of the bitemark is conditional on the suspect's profile when he/she is also not the biter. But if the suspect is not the biter, he/she and his/her profile should then not be counted in: Someone did make the bitemark, but if the suspect is not the biter then he/she should be abstracted from the suspect-population.

$$V = \frac{P(bmi2_{cbm} | bmi1_{sbm}, BM1_1)}{P(bmi2_{cbm} | BM1_0)}.$$

The probability of the bitemark-profile conditional on the suspect not being the biter can be estimated by the proportion of the general relevant population of biting-mechanisms (with any profile) which could possibly make bitemarks with profiles similar to that of the bitemark in question. This proportion is sometimes called "the random match-probability".

This relationship between  $BN1_j$ ,  $bmi1_{sbm}$ , and  $bmi2_{cbm}$  may be called a *converging* relationship in which, according to the corresponding rule of d-separation, effect cannot not be transmitted between  $BM_j$  and  $bmi1_{sbm}$  if nothing is reported on the state of  $bmi2_{cbm}$  (or one of its descendants). When information about the profile of the bitemark is included the channel between  $BN1_j$  and  $bmi1_{sbm}$  opens and effect may be transmitted. This conditional dependence-relationship may be graphically displayed as in figure 10.2 — in which the conditional dependence is expressed by having removed the arrow between  $BM1_1$  and  $bmi1_{sbm}$ :

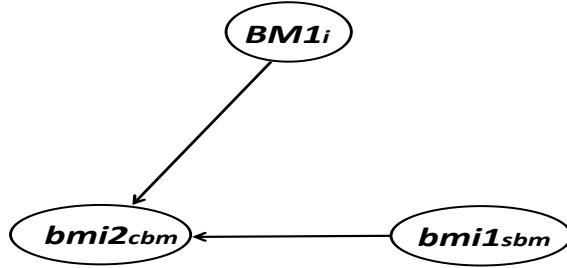


Figure 10.2: A partial bitemark-DAG limited to the diagnosis of the bitemark with respect to the suspect's versus others' biting-mechanism.

### Diagnosing the bitemark's most likely time of occurrence

The second source-level question is whether the bitemark was made simultaneously with the control-injury (an injury known to be a direct effect of the legal injury): Either the bitemark was made at the same time as the control-injury or not. Above these two possibilities were denoted by  $BM2_1$  and  $BM2_0$  respectively:

$BM2_1$ : "The bitemark was caused simultaneously with control-injury;

$BM2_0$ : "The bitemark was not caused simultaneously with the control-injury.

The bitemark and the control-injury are assessed and observed via different technical heuristics and categorized on  $TI$  to have profiles  $ti_{cbm}$  and  $ti_{li}$ , respectively. The likelihood-ratio is then

$$V = \frac{P(ti_{cbm}, ti_{li} \mid BM2_1)}{P(ti_{cbm}, ti_{li} \mid BM2_0)}.$$

By the third law of probability this may be expressed as

$$V = \frac{P(ti_{cbm} \mid ti_{li}, BM2_1) P(ti_{li} \mid BM2_1)}{P(ti_{cbm} \mid ti_{li}, BM2_0) P(ti_{li} \mid BM2_0)}.$$

What is the nature of the relationship expressed in the second term on the right hand side of this equation —  $P(ti_{li} | BM2_1)/P(ti_{li} | BM2_0)$ ? Whether the bitemark was made at the same time-interval or not as the control-injury cannot change the time-profile of the control-injury. The profile is what it is independent of whether the bitemark was made simultaneously with it or not;  $P(ti_{li} | BM2_1) = P(ti_{li} | BM2_0)$ ;

$$V = \frac{P(ti_{cbm} | ti_{li}, BM2_1)}{P(ti_{cbm} | ti_{li}, BM2_0)}.$$

The numerator of the remaining term on the right side states that the probability of the time-profile of the bitemark is conditional on the time-profile of the control-injury when these also did occur simultaneously. It is possible to agree that this event cannot be further simplified.

The denominator of the remaining term on the right side states that the probability of the profile of the bitemark is conditional on the time-profile of the control-injury when these also did not occur simultaneously. There is no causal influence in this scenario, but a logical one: The time of the control-injury cannot cause the time of occurrence of the bitemark, but conditions by disallowing a state similar to the control-injury. The denominator stays unchanged:

$$V = \frac{P(ti_{cbm} | ti_{li}, BM2_1)}{P(ti_{cbm} | ti_{li}, BM2_0)}.$$

The relationship between  $BM2_j$ ,  $ti_{li}$ , and  $ti_{cbm}$  is also a *converging* relationship.  $BM2_j$  and  $ti_{li}$  are d-separated if nothing is reported on the state of  $ti_{cbm}$  (or one of its descendants); but if information about the time-profile of the bitemark is included then effect can be transmitted between  $BM2_j$  and  $ti_{li}$ . This conditional dependence-relationship may be graphically displayed as in figure 10.3 — in which the conditional dependence is expressed by having removed the arrow between  $BM2_j$  and  $ti_{li}$ :

### 10.3.2 The activity- and the crime-levels of the problem

The last relationship to be considered is that between  $BM_j$ ,  $BM1_j$ , and  $BM2_j$ : Either the bitemark was made by the suspected individual simultaneously with the legally relevant injuries or not. Above these two possibilities

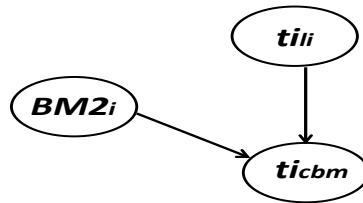


Figure 10.3: A partial bitemark-DAG limited to the diagnosis of the bitemark with respect to having occurred simultaneously or not with control-injury.

were denoted by  $BM_1$  and  $BM_0$  respectively (the latter being a composite event):

$BM_1$ : "The suspect made the bitemark simultaneously with the legally relevant injuries",

$BM_0$ : "The suspect did not make the bitemark or the bitemark was made by the suspect or another person at an occasion irrelevant to the legally relevant injuries."

At the source-level, for both profiling-purposes, it was rather easy to decide that it was the probability of profile of bitemark which was the primary question. At the activity- and the crime-level it is less easy to determine the primary question — neither causality nor logic may help us. An ad hoc principle which does not affect the results will be resorted to: Because the question of simultaneity is a recurrent question in any forensic means of evidence problem but the question of the suspect being the biter or not is particular to bitemark-means of evidence, the latter will be chosen as the probability of primary concern. The relationship of interest then is:

$$\frac{P(BM1_j | BM2_j, BM_1)}{P(BM1_j | BM2_j, BM_0)} \frac{P(BM2_j | BM_1)}{P(BM2_j | BM_0)}$$

What is the nature of the relationship expressed in the second term of the above expression —  $P(BM2_j | BM_1)/P(BM2_j | BM_0)$ ? Is the state of  $BM2_j$  dependent on the state of  $BM_j$ ? If the latter is in the state  $BM_1$ , then the probabilities of having  $BM2_1$  and  $BM2_0$  is 1 and 0 respectively: If the suspect is the agent then the bitemark must have been simultaneous and then its complement is impossible. What if  $BM_j$  is in its state  $BM_0$ ? If  $BM_j$  is in the state  $BM_0$  and  $BM2_j$  is in state  $BM2_0$  this means that either the suspect or someone else made the bitemark at a time irrelevant to the crime event. If  $BM2_j$  is in state  $BM2_1$  it means that the bitemark was made by the offender simultaneously with the crime event, but not by the identified suspect. It is tempting to set  $P(BM2_1 | BM_0) = P(bmi2_{cbm} | (bmi1_{\neg sbm} \cup \neg bmi_{\neg sbm}, BM1_0))$ . But then  $P(BM2_0 | BM_0)$  must be  $1 - P(bmi2_{cbm} | (bmi1_{\neg sbm} \cup \neg bmi_{\neg sbm}, BM1_0))$  which excludes the possibility that the identified suspect could have made the bitemark. Another interpretation is to see  $P(BM2_1 | BM_0) = P(BM2_0 | BM_0)$ : That when the suspect is not the agent the question of the identity of the offender becomes irrelevant to the question about the simultaneity of the two skinmarks. I will proceed with the latter solution, but I am not sure if I understand this properly — I am not able to justify it very well.

The relationship  $P(BM2_j | BM_1)/P(BM2_j | BM_0)$  is one of conditional dependence and cannot be further simplified.

What about the first term  $P(BM1_j | BM2_j, BM_1)/P(BM1_j | BM2_j, BM_0)$ ?

- If the suspect is the offender and the bitemark was made simultaneously with the crime act, then the suspect's biting-mechanism must be the cause of the bitemark:  $P(BM1_1 | BM2_1, BM_1) = 1$ .  
Then  $P(BM1_0 | BM2_1, BM_1) = 0$ ; and
- if the suspect is the offender but the bitemark was made at another event irrelevant to the crime event, then the probability that the suspect's biting-mechanism is the cause of the bitemark can be estimated by the time-independent probability of it being the cause. I will denote this probability by  $\beta$ :  $P(BM1_1 | BM2_0, BM_1) = \beta$ .  
Then  $P(BM1_0 | BM2_0, BM_1) = 1 - \beta$ ; and

- If the suspect is not the offender and the bitemark was made simultaneously with the crime act, then the suspect's biting-mechanism can not be the cause of the bitemark:  $P(BM1_1 | BM2_1, BM_0) = 0$ . Then  $P(BM1_0 | BM2_1, BM_0) = 1$ ; and
- if the suspect is not the offender and the bitemark was made at another event irrelevant to the crime event, then the probability that the suspect's biting-mechanism is the cause of the bitemark can be estimated by the time-independent probability of it being the cause. This probability was above denoted by  $\beta$ . Then  $P(BM1_0 | BM2_0, BM_1) = 1 - \beta$ .

The relationship between  $BM_j$ ,  $BM2_j$ , and  $BM1_j$ , is thus also a *converging* relationship.  $BM_j$  and  $BM2_j$  is d-separated if nothing is known about the state of  $BM1_j$  or its descendant  $bmi2_{cbm}$ . Receiving information about the BMI-profile of the bitemark will then open for effect to travel between  $BM2_j$  and  $BM_j$ . This final bitemark-DAG is displayed in figure 10.4.

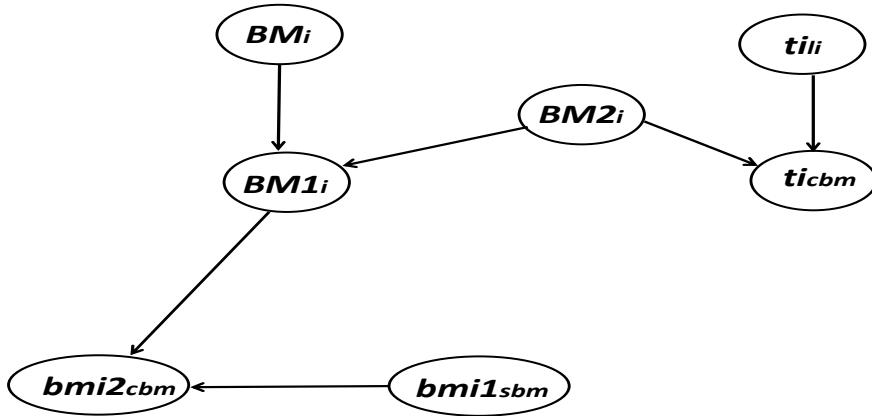


Figure 10.4: The final bitemark-DAG for the bitemark problem.

These assessments and the final result are analogue to those made by Taroni et al. when they considered the relationships between the events relevant in a one-offender shoe-imprint scenario (Taroni et al. 2006: 101-103). A

shoe-imprint is similar to a bitemark in human skin by the indirect relationship between the forensic markers of the shoe and those of the imprint. But it is different in one respect: The suspected shoe only indirectly can be used to connect the suspected person to the place of the crime as the shoe is not a part of the body of the person in the way a biting-mechanism is (in the case of natural teeth). A bitemark-problem is thus simpler than a shoe-imprint problem in that you avoid having to account for the events made possible due to the shoe not being integral to the body of a person.<sup>2</sup>.

In addition I have altered both the name and the formulation of the event which Taroni et al. (2006: 103) label the "relevance"-term: They prefer to formulate it as "The offender left the imprint" while I prefer "The imprint was made simultaneously with the legally relevant injury". Their aim, I anticipate, given their labelling of this diagnosis-event or criterion as the *relevance*-event, is to stress the event's role as a constantly recurring kind of event in any forensic problem at the action-level. I have no methodological issue with this and also agree that it might be a better pedagogical solution than mine is. My aim is to bring out the point that this event is the test whether the imprint and a known observable effect of the legal act is connected in *time* — while the other diagnostic event or criterion, whether the suspect, via the forensic item observed, is the causal agent of the imprint, is the test whether the imprint and the suspect connects in *space*. Both tests are logically or causally necessary, and equally so, in any forensic problem. But my specification is less transparent than Taroni et al.'s — I run into certain logical complications which makes it not the wisest way in which to communicate the roles of the diagnostic criteria to new students of forensic science. The main point is, however, that my choice of relationships for the events of the bitemark-problem has support in the fact that Taroni et al. (2006) arrived at the same solution for the shoe-imprint problem.

In the next section we will see how my choice of relationships affects the derivation of the general likelihood-ratio for the kind of bitemark-problems studied in this dissertation.

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<sup>2</sup>Taroni et al (2006) also assumed that the imprint could not have been made by the suspect's shoe by the suspect at another time. I relaxed this assumption and suggested it estimated by the time-independent probability that the suspect's biting-mechanism is the causal object of the bitemark (complemented by the probability of another person's bitemark being the causal object)

## 10.4 Deriving the likelihood-ratio for the bitemark-problem

The likelihood-ratio has two functions: When substantiated by case information and calculated, it may be interpreted as a practical indication of the evidential value of the bitemark; but its real function is methodological — to evidence-base the crime investigator's decision about case-conditioned relevance to the standard specified in the first chapter of this dissertation.

The crime investigator's primary concern or question can be represented by the following initial likelihood-ratio:

$$\frac{P(bmi2_{cbm} | bmi1_{sbm}, BM_1)}{P(bmi2_{cbm} | bmi1_{sbm}, BM_0)} \quad (10.5)$$

I will start with the numerator first.

$$P(bmi2_{cbm} | bmi1_{sbm}, BM_1) =$$

$$\begin{aligned} & P(bmi2_{sbm} | bmi1_{sbm}, BM_{11}, BM_1)P(BM_{11} | bmi1_{sbm}, BM_1) \quad (10.6) \\ & + P(bmi2_{cbm} | bmi1_{sbm}, BM_{10}, BM_1)P(BM_{10} | bmi1_{sbm}, BM_1). \end{aligned}$$

First, according to assumptions in the previous section:

- $BM_1$  screens off  $bmi2_{cbm}$  from  $BM_j$  (and  $BM_{2j}$ ):  
 $P(bmi2_{cbm} | bmi1_{sbm}, BM_{11}, BM_1) = P(bmi2_{cbm} | bmi1_{sbm}, BM_{11})$ ;  
and
- having no knowledge of the profile of the bitemark,  $bmi2_{cbm}$ , makes the uncertainty about  $BM_1$  unaffected by knowledge about the suspect's biting-mechanism's profile,  $bmi1_{sbm}$ .

Then

$$\begin{aligned} P(bmi2_{cbm} | bmi1_{sbm}, BM_1) &= \\ & P(bmi2_{cbm} | bmi1_{sbm}, BM_{11})P(BM_{11} | BM_1) \quad (10.7) \\ & + P(bmi2_{cbm} | bmi1_{sbm}, BM_{10})P(BM_{10} | BM_1). \end{aligned}$$

Accounting for  $BM2$ :

$$\begin{aligned} P(BM1_1 \mid BM_1) &= \\ P(BM1_1 \mid BM2_1, BM_1)P(BM2_1 \mid BM_1) + & (10.8) \\ P(BM1_1 \mid BM2_0, BM_1)P(BM2_0 \mid BM_1) \end{aligned}$$

and

$$\begin{aligned} P(BM1_0 \mid BM_1) &= \\ P(BM1_0 \mid BM2_1, BM_1)P(BM2_1 \mid BM_1) + & (10.9) \\ P(BM1_0 \mid BM2_0, BM_1)P(BM2_0 \mid BM_1) : \end{aligned}$$

- If the suspect is the offender and the bitemark was made simultaneously with the crime act, then the suspect's biting-mechanism must be the cause of the bitemark:  $P(BM1_1 \mid BM2_1, BM_1) = 1$ .  
Then  $P(BM1_0 \mid BM2_1, BM_1) = 0$ ; and
- if the suspect is the offender but the bitemark was made at another event irrelevant to the crime event, then the probability that the suspect's biting-mechanism is the cause of the bitemark can be estimated by the time-independent probability of it being the cause. Denote this probability by  $\beta$ :  $P(BM1_1 \mid BM2_0, BM_1) = \beta$ .  
Then  $P(BM1_0 \mid BM2_0, H_1) = 1 - \beta$ ; and
- $BM2$  and  $BM$  are probabilistically independent,

so

$$P(BM1_1 \mid BM_1) = P(BM2_1) + \beta P(BM2_0) \quad (10.10)$$

and

$$P(BM1_0 \mid BM_1) = (1 - \beta)P(BM2_0). \quad (10.11)$$

**The numerator is now:**

$$\begin{aligned} & P(bmi2_{cbm} | bmi1_{sbm}, BM1_1)[P(BM2_1) + \beta P(BM2_0)] \\ & + P(bmi2_{cbm} | bmi1_{sbm}, BM1_0)[(1 - \beta)P(BM2_0)] \end{aligned} \quad (10.12)$$

**Then the denominator:**

$$\begin{aligned} & P(bmi2_{cbm} | bmi1_{sbm}, BM_0) = \\ & P(bmi2_{cbm} | bmi1_{sbm}, BM1_1, BM_0)P(BM1_1 | bmi1_{sbm}, BM_0) \quad (10.13) \\ & + P(bmi2_{cbm} | bmi1_{sbm}, BM1_0, BM_0)P(BM1_0 | bmi1_{sbm}, BM_0). \end{aligned}$$

$$\begin{aligned} & P(bmi2_{cbm} | bmi1_{sbm}, BM_0) = \\ & P(bmi2_{cbm} | bmi1_{sbm}, BM1_1, BM_0)P(BM1_1 | BM_0) \\ & + P(bmi2_{cbm} | bmi1_{sbm}, BM1_0, BM_0)P(BM1_0 | BM_0). \end{aligned}$$

Accounting for  $BM2$ :

$$\begin{aligned} P(BM1_1 | BM_0) &= P(BM1_1 | BM2_1, BM_0)P(BM2_1 | BM_0) + \\ & P(BM1_1 | BM2_0, BM_0)P(BM2_0 | BM_0) \end{aligned} \quad (10.14)$$

and

$$\begin{aligned} P(BM1_0 | BM_0) &= P(BM1_0 | BM2_1, BM_0)P(BM2_1 | BM_0) + \\ & P(BM1_0 | BM2_0, BM_0)P(BM2_0 | BM_0) \end{aligned} \quad (10.15)$$

- If the suspect is not the offender and the bitemark was made simultaneously with the crime act, then the suspect's biting-mechanism can not be the cause of the bitemark:  $P(BM1_1 | BM2_1, BM_0) = 0$ . Then  $P(BM1_0 | BM2_1, BM_0) = 1$ ; and
- if the suspect is not the offender and the bitemark was made at another event irrelevant to the crime event, then the probability that the suspect's biting-mechanism is the cause of the bitemark can be estimated

by the time-independent probability of it being the cause. This probability was above denoted by  $\beta$ :  $P(BM1_1 | BM2_0, BM_1) = \beta$ . Then  $P(BM1_0 | BM2_0, BM_1) = 1 - \beta$ ; and

- $BM2_j$  and  $BM_j$  are probabilistically independent,

so

$$P(BM1_1 | BM_0) = \beta P(BM2_0) \quad (10.16)$$

and

$$P(BM1_0 | BM_0) = P(BM2_1) + (1 - \beta)P(BM2_0). \quad (10.17)$$

**The denominator is now:**

$$\begin{aligned} & P(bmi2_{cbm} | bmi1_{sbm}, BM1_1)[\beta P(BM2_0)] \\ & + P(bmi2_{cbm} | bmi1_{sbm}, BM1_0)[P(BM2_1) + ((1 - \beta)P(BM2_0))]. \end{aligned} \quad (10.18)$$

- $P(bmi2_{cbm} | bmi1_{sbm}, BM1_0) = P(bmi2_{cbm} | BM1_0)$

**The overall LR:**

$$LR = \frac{P(bmi2_{cbm} | bmi1_{sbm}, BM1_1)[P(BM2_1) + \beta P(BM2_0)] + P(bmi2_{cbm} | BM1_0)[(1 - \beta)P(BM2_0)]}{P(bmi2_{cbm} | bmi1_{sbm}, BM1_1)[\beta P(BM2_0)] + P(bmi2_{cbm} | BM1_0)[P(BM2_1) + ((1 - \beta)P(BM2_0))]} \quad (19a)$$

Some simplifications may be made:

- $P(bmi2_{cbm} \mid BM1_0)$  is the "random match" probability — the probability of observing the bitemark of this profile if someone else's biting-mechanism is the causal object of the bitemark: This may be denoted by  $\gamma$ ;
- $P(BM2_1)$  is the probability that the bitemark was made simultaneously with the legally relevant injury: This may be denoted by  $sim$ . The complement  $P(BM2_0)$  is then equal to  $1 - sim$ .

$$LR = \frac{P(bmi2_{cbm} \mid bmi1_{sbm}, BM1_1)[sim + \beta(1 - sim)] + \gamma[(1 - \beta)(1 - sim)]}{P(bmi2_{cbm} \mid bmi1_{sbm}, BM1_1)[\beta(1 - sim)] + \gamma[sim + ((1 - \beta)(1 - sim))]} \quad (10.19)$$

## 10.5 Conclusion

Renaming  $LR$  as  $V_{BM}$ , to signify "value of bitemark-means", the crime investigator's bitemark-problem in the specified situation may thus be formally represented as the following:

If the options of the crime investigator is to decide either "strictly positively relevant", denoted by  $a_1$ , or "not strictly positively relevant", denoted by  $a_0$ , if there for each of  $a_i$  exist  $BM_j$  of mutually exclusive and exhaustive events, and if there exist consequences  $c_k$  associated with  $a_i$ , then the crime investigator can decide  $a_1$ , positive relevance, if and only if

$$\bar{u}(a_1 \mid P(BM_j \mid V_{BM}, K_0)) > \bar{u}(a_0 \mid P(BM_j \mid V_{BM}, K_0)),$$

The claim in this dissertation is that this representation of the bitemark-problem will ensure evidence-based decisions about the relevance of bitemark-means — conditional on the problem being representative of the context being of the kind specified and denoted by  $K_0$ .

In the next chapter I will study how this interpretation of the bitemark-problem may be exploited in a practical bitemark-problem.

# Chapter 11

## A practical example: A bitemark-problem similar to that of the Torgersen-case

In this chapter I will perform a  $BN_s$ -analysis of a crime investigative bitemark-problem approximating that of the Torgersen-case. I borrow some of the reality of that case, but will assume (a) that only four characteristics were used for diagnosing the most likely causal biting-mechanism of the bitemark; (b) that a unspecified set of markers was used for diagnosing the simultaneity between the bitemark and the control-injury; and (c) that certain specifications and distributions hold for the characteristics and for the accuracy of the experts diagnosing via these.

The purpose is to demonstrate how the methodology and the model suggested in the previous chapter work in an approximately real bitemark-situation — to demonstrate how a crime-investigator in practice may secure an evidence-based decision about a bitemark-means' relevance to a legal indictment.

It is important to stress that the results of this analysis will *not* be valid for the Torgersen-case: (1) in that case the experts did observe the four characteristics I include, but they also observed others as well (some explicit in the written reports, but ill-defined, and, most likely, some implicit); (2) the specifications and distributions I suggest for the four characteristics and for the expert-accuracies are not expert-based, but based on my judgment that the characteristics are reasonably similar to characteristics which have been studied, with respect to expected expert-consensus about specification

and distribution; (3) the decision in the Torgersen-case concerned the relevance of the *bitemark-means* while my decision concerns the relevance of the *bitemark-proposition* — about the physical but not the motivational aspects of the causal mechanism behind the biting. I should therefore add the following "will":

I will not allow the results of this analysis in this chapter to be used for any legal or legal-political strategic or tactical purposes related to neither the Torgersen-case nor other similar cases. I will, however, allow the results of the other chapters to be used for any purpose.

## 11.1 Assumptions about the relevant events, consequences, and options

In this chapter I will illustrate the reasoning of a crime-investigator having a real bitemark-problem and who has chosen to use the  $BN_s$ -approach and my model of the problem. I will borrow the reality of the bitemark-problem in the Torgersen-case from part II of this dissertation, using the information provided in Eskeland (2000 and 2005) and Review Commission (2006), complement with information provided in the published literature, and the following assumptions about the investigator's situation:

### **Assumption 1. The context:**

I will assume that the context of the case is representative of that specified in the first section of the previous chapter and denoted by  $K_0$ .  $K_0$  differs from the Torgersen-case in that it only allows bitemark-means to be a corroborating means of evidence while it in the Torgersen-case was a necessary means of evidence.

### **Assumption 2. The decision-problem:**

The decision-problem of the case will be assumed to be representative of that specified in the previous chapter: Having the same relevant propositions/events, consequences, and decision-options. The denotations for these elements will be kept, but particularized to indicate the individuals (persons, forensic items, etc.) of the case;

**Assumption 3. The expert-recommendations with respect to  $BM1$ :**

It will be assumed that the bitemark-experts have reported that the suspect's biting-mechanism has a  $BM1$ -profile compatible with the  $BM1$ -profile of the bitemark and that they have recommended that the suspect's biting mechanism is "very likely" the cause of the bitemark.  $BM1_j$  is thus recommended to be in state  $BM1_1$ . This corresponds with the Torgersen-case.

**Assumption 4. The expert-recommendations with respect to  $BM2$ :**

It will be assumed that the bitemark-experts and the forensic medical examiner agree that the bitemark has a  $TI$ -profile compatible with the  $TI$ -profile of the control-injury and that  $BM2_j$  is in state  $BM2_1$ . This does not correspond to the Torgersen-case. In that case the diagnostic criterion of simultaneity was not explicitly questioned or assessed.

**Assumption 5. The profiling for diagnosing causal object of bitemark**

The characteristics included in the  $BM1$ - and  $BM2$ -instruments used by the Torgersen-experts were difficult to elicit due to incompleteness and imprecision of the written reports. It was particularly difficult to identify the components of  $BM2$  (the set of characteristics used for profiling the bitemark). It is however certain that the Torgersen-experts observed the following characteristics when diagnosing the causal biting-mechanism of the bitemark:

- *Kind and degree of wear* (hereafter: *wear*);
- *Kind and degree of rotation/position* (hereafter: *rotation/position*);
- *Existence of object in position 4a for the bitemark and 42 for the suspect's biting-mechanism* (hereafter: *existence 4a(42)*);
- *kind of labio-lingual relationship between the objects in positions 5 and 6 for the bitemark and positions 41 and 31 for the suspect's biting-mechanism* (hereafter: *labio-lingual 5,6(41,31)*):

With respect to *wear* and *rotation/position* the experts most likely observed these of both individual and sub-groups of skinmarks and teeth, but, again due to the incomplete and imprecise reports, I will have to let the profiles on *wear* and *rotation/position* refer to the macro-units — the bitemark

and the biting-mechanism. The profiles on existence 4a(42) and *labio-lingual* 5,6(1,41) refer to subunits — to one or two individual marks and teeth.

These four characteristics will constitute the *BMI1*- and *BMI2*-instruments used by the expert in my illustrative case. The discriminatory power via these instruments will thus be different from those used in the Torgersen-case. The results from the analyses of this chapter can therefore not be reason or evidence for or against any claim that the Torgersen-experts' conclusions were wrong: My purpose is solely to exemplify a different analytical procedure.

Further assumptions must be made about (a) how the experts observed the four characteristics of the bitemark and the biting-mechanism; (b) the characteristics' distribution in the relevant population; and the expert's diagnostic accuracy when using these characteristics.

**Assumption 5a. *BMI1m* and *BMI2m*: Observing and classifying the bitemark and the suspect's biting-mechanism with respect to *rotation/position*** The Torgersen-experts referred both to *positioning* and *rotation* of some of the individual teeth and skinmarks relative to archs formed by groups of such. It is not clear from the expert-reports whether *mesio-distal rotation* was separated from *labio-lingual* position. My *rotation/position* does not differentiate either. Neither is it clear how the experts classified each tooth and mark with respect to these characteristics, but both the bitemark and the suspect's biting-mechanism were found to be *regular*. The Torgersen-experts did not opine about the proportion of any relevant population having biting-mechanisms being *regular* on *rotation/position*. Nor did they opine on the kind and degree of distortion or deviance between the *rotation/position*-profile observed of biting-mechanisms at rest and that of bitemarks on human skin at rest — after having been affected by processes (such as teeth-mobility, jaw-mobility, force and direction of biting, and skin's visco-elasticity) activated during the biting-process. And, finally, the experts did not provide any estimate for the possibility that they could be wrong. They did express that they could never be absolutely certain, but did not address (a) the probability that any of the profiles ascribed to the samples were wrong; (b) the probability that the compatibility-conclusion was a false positive, or (c) the probability that another biting-mechanism from any reference-population, with the same or different *rotation/position*-profile as the suspect, could have made the profile of the bitemark. And,

finally, the Torgersen-experts did not inform whether they were subject to any accreditation schemes beyond the most general. I have found no sign in the literature that European or other forensic bitemark-experts are regularly accredited with respect to diagnostic accuracy with or without specific forensic markers. The experts did not appeal to any such to support their claim of accuracy in the Torgersen-case.

To pursue the illustration of the methodology and the model from the previous chapters I will have to make some assumptions. I will assume that

- 5a1. the experts used the instruments of  $BMI1m$  and  $BMI2m$  when classifying the *rotation/position*-configuration of the biting-mechanism and the bitemark respectively;
- 5a2. they reported the suspect's biting-mechanism to have profile  $BMI1m = bmi1m_{sbm}$  and the bitemark to have profile  $BMI2m = bmi2m_{cbm}$ ;
- 5a3. these two profiles are the objects' true profiles (no false positives/negatives for these decisions). This assumption is done for simplifying purposes;
- 5a4. the proportion of biting-mechanisms in the relevant population sharing the same  $bmi1m$ -profile as the suspect is 40% and the proportion with a different profile,  $\neg bmi1m$ , is 60%. This distribution is justified by (a) my belief that a *rotation/position* of *regular* is not an uncommon condition in the relevant population (biting-mechanisms in Oslo 1958), and (b) my belief that others would agree to this belief and to the suggested distribution;
- 5a5. of all the biting-mechanisms which will cause  $bmi2m$ -bitemarks, 80% will have the same profile as the suspect,  $bmi1m$ , and 20% will have a different profile,  $\neg bmi1m$ . The justification for this distribution is (a) my belief that the profile observed of the bitemark is the effect of not only the profile of the causal biting-mechanism but also of the mechanisms activated during the biting-process, (b) my belief that if a bitemark is classified to have medium forensic significance on the Pretty-scale (see specification of  $K_0$  in chapter 9, section 2), then the difference due to distortion should be moderate;

**5a6.** the experts, their perceptions and observations of *rotation/position*, and the diagnostic situation are representative of those in the accuracy-studies existing for diagnosis via *rotation/position* (see chapter 7):

- via *rotation/position* alone, the experts are able to identify the true causal biting-mechanism 80% of the times and are able to identify the true negative causal biting-mechanism 80% of the times.
- the experts thus have a false positive rate of 20% and a false negative rate of 20%.

This distribution is justified by (a) my belief that the Torgersen-experts' diagnostic situation was similar to that of the accuracy-studies using a similar notion of *rotation/position* and (b) my belief that if a bitemark is classified to have medium forensic significance on the Pretty-scale (see specification of  $K_0$  in chapter 9, section 2), then the risk of misdiagnosis should be moderate.

**Assumption 5b. *BMI1a* and *BMI2a*: Observing and classifying the bitemark and the suspect's biting-mechanism with respect to wear**

The Torgersen-experts reported that at least five of the individual marks in the bitemark had symptoms indicating that the causal biting-mechanism must have been worn in a specific way and degree — a condition caused by the biting-mechanism having a particular occlusion-condition ("edge-to-edge"). The symptoms were only described in terms of the causal teeth-characteristics such as *furrowing* and *splintering*. It is not clear if or how they differentiated these symptoms from those expected when the causal biting-mechanism has another kind (by another cause, such as food-habits, medication/drug-abuse, or disease) or degree of wear. The experts classified the suspect's biting-mechanism as *very worn of a kind caused by occlusion being edge to edge* with respect to wear. Only after repeated questioning did the experts opine that if the suspect could be assumed to be a member of the sample studied by Smith and Robb (1996) (a prevalence-study of a related characteristic) then the suspect's degree of wear would have been classified as *very uncommon* — a degree of wear shared by 5.3% of that sample.

As for *rotation/position* the experts did not address the issue of the relationship between wear of the biting-mechanism at rest and symptoms of such

of the bitemark at rest, after having been exposed to further mechanisms during the biting. And, finally, the experts did not provide any estimates of the possibilities that (1) they were wrong about (a) the wear-classification of the suspect's biting-mechanism or the bitemark or (b) the decision that the suspect's wear and the bitemark's symptoms of such were compatible and that (2) that another biting-mechanism with same or different wear-profile as the suspect's could have made the profile of the bitemark. Again, to pursue the illustration of the methodology and the model from the previous chapters, I will have to make assumptions: I will assume that

- 5b1.** the expert in my case used the instruments of  $BMI1a$  and  $BMI2a$  when classifying the *kind and degree of wear*-configuration of the biting-mechanism and the bitemark respectively;
- 5b2.** they reported the suspect's biting-mechanism to have profile  $BMI1a = bmi1a_{sbm}$  and the bitemark to have profile  $BMI2a = bmi2a_{cbm}$ ;
- 5b3.** these two profiles are the objects' true profiles (no false positives/negatives for these decisions). This assumption is done for simplifying purposes.
- 5b4.** the proportion of biting-mechanism in the relevant population for the case sharing the same  $bmi1m$ -profile as the suspect will be 5% and the proportion with a different profile,  $\neg bmi1m$ , will be 95%. This distribution is justified by (a) the assumption that the population of the suspect's biting-mechanism is sufficiently similar to that of Smith and Robb (1996)'s sample. I am not able to judge whether this is a reasonable assumption or not: The court-appointed experts on the Torgersen-case claimed that the suspect's kind and degree of wear was rare, but the defence-experts claimed it to be rather common in the population relevant for the Torgersen-case. My choice that my suspect's wear-profile is shared by 5% of the relevant population is motivated solely by the purpose of illustrating the methodology and the model and does not aspire to be any best estimate;
- 5b5.** of all the biting-mechanisms which will cause  $bmi2a$ -profiled bitemarks, 80% will have profile  $bmi1a$  (similar to suspect) and 20% will have a different profile,  $\neg bmi1a$ . The justification for this distribution is (a)

my belief that the profile observed of the bitemark is the effect of not only the biting-mechanism but also of the mechanisms activated during the biting-process and (b) my belief that if a bitemark is classified to have medium forensic significance on the Pretty-scale (see chapter 7, section 2) then the difference due to distortion should be moderate;

**5b6.** the expert's diagnostic situation are representative of those of the accuracy studies (see chapter seven) involving a characteristic assumed to be both conceptually and observationally sufficiently similar to that of the experts on the Torgersen-case:

- via the *kind and degree of wear*-instrument alone, the experts are able to identify the true biting-mechanism 60% of the times and the true negative biting-mechanism 60% of the times.
- the experts thus have a false positive rate of 40% and a false negative rate of 40%.

This distribution is justified by (a) the belief that the Torgersen-experts' diagnostic situation was similar to those of the accuracy-studies involving similarly ill defined characteristics, particularly the characteristic of *area* (Martin-de las Heras et al. (2007)) and (b) the belief that even if a bitemark is classified to have medium forensic significance on the Pretty-scale (see specification of  $K_0$  in chapter nine) the risk of misdiagnosis should be larger than that of *rotation/position*.

Available studies indicate that *rotation/position* is a simpler phenomenon, easier to agree on, than that of *area*. Firstly, Martin-de las Heras et al. (2007) is direct evidence of this as is the similar specification of *rotation/position* in Martin-de las Heras et al. (2007), Rawson et al. (1984), and Bernitz et al. (2005). A specification found useful by three studies might not seem much, but in bitemark-analysis it is. Secondly, *area* was not uniformly perceived despite perception-guidelines (Martin-de las Heras et al. (2007)). And thirdly *kind and degree of wear* is suspected to be even more prone to varying perceptions than *area*, particularly as no observation guideline or standard exists: No study of any kind even mentions *wear* as a possibly relevant characteristic in bitemark-analysis, while both *rotation/position* and *area* are among the most frequently mentioned and studied (together with *inter-canine-distance* and *missing teeth*).

The justifications for my choices about diagnostic accuracy via wear are thus not solid and should not be used for practical purposes. They may, however, be used for the purpose of this chapter, to illustrate alternative methodology.

**Assumption 5c. *BMI142 and BMI24a: Observing and classifying the bitemark and the suspect's biting-mechanism with respect to existence of object in position 4a and 42 respectively.*** In the Torgersen-case the question about the existence of a sub-mark between the sub-marks nr. 4 and 5 was a central issue. All the experts involved across time and parties agreed that there was a space between the sub-marks nr. 4 and 5: all the court-appointed experts agreed that the submarks nr. 4, 5, and 6 had been caused by teeth 43, 41, and 31, respectively. Only after repeated questioning by the defense did the modern court-appointed experts state that a suspect having tooth 42 present is compatible with having a bitemark without a clear impression from that tooth: Particularly if tooth 42 was smaller than the adjacent teeth 41 and 43 would this be possible. Torgersen's biting-mechanism had a 42 slightly smaller than both 41 and 43. The expert-witnesses assisting the defense disagreed: They claimed there to be *no* mark in position 4a and that this is only possible if the causal biting-mechanism either did not have a tooth 42 or that this tooth was severely damaged. Senn (1999) argued that his experiment with a model claimed to be from the suspect's teeth consistently made a mark when pressed into dental wax. But the authenticity of that model became questioned and none of the experts opined on the mobility of teeth in general or the mobility of Torgersen's 42 in particular. And they clearly disagreed about the skin's ability to register impact from teeth 42 of a kind similar to that of Torgersen. None of the experts opined on the prevalence of absent, damaged, or small tooth 42 in any relevant population. And, by December 2008, no studies of the effect of mechanisms activated during the biting-process existed. Finally, the experts did not provide any estimates for the possibilities that their classifications or diagnoses were wrong. To pursue the illustration of the methodology and the model from the previous chapters will assume that

**5c1.** the experts used the instruments of *BMI142* and *BMI24a* when classifying *existence42* of the biting-mechanism and *existence4a* the bitemark respectively;

**5c2.** they reported the suspect's biting-mechanism to have profile  $BMI142 = bmi142_{sbm}$  and the bitemark to have profile  $BMI24a = bmi24a_{cbm}$ ;

**5c3.** these two profiles are the objects' true profiles (no false positives/negatives for these decisions). This assumption is done for simplifying purposes.

**5c4.** the proportion of biting-mechanisms in the relevant population sharing the same  $bmi142$ -profile as the suspect is 50% and the proportion with a different profile,  $\neg bmi142$ , is 50%. This distribution is justified by the lack of information about this characteristic in the relevant population (biting-mechanisms in Oslo 1958).

**5c5.** of all the biting-mechanisms which will cause  $bmi24a$ -profiled bitemarks, 50% will have the same profile as the suspect,  $bmi142$ , and 50% will have a different profile,  $\neg bmi142$ . The justification for this distribution is (a) the inability to discriminate between the available expert-information about this relationship.

**5c6.** the experts, their perceptions and observations of *existence 4a* and *existence 42* under in conditions similar to those of the Torgersen-case, have a very poor accuracy:

- via *existence4a* and *existence42* alone, the experts are able to identify the true biting-mechanism 50% of the times and the true negative biting-mechanism 50% of the times.
- the experts thus have a false positive rate of 50% and a false negative rate of 50%.

This distribution is justified by the lack of agreement/knowledge among experts and studies about the effects of mechanisms activated during the biting-process — the expert-knowledge provides no more information than the tossing of a coin.

**Assumption 5d. *BMI131, 41 and BMI25, 6: Observing and classifying the bitemark and the suspect's biting-mechanism with respect to labio-lingual relationship between sub-marks 5 and 6 and between teeth 41 and 31:*** In the Torgersen-case the question about the

labio-lingual relationships between the sub-marks nr. 5 and 6, and that of the suspect's teeth 41 and 31 became an issue. All the experts involved across time and parties agreed that the marks were labio-lingually related oppositely that of the suspect's teeth. Again, only after repeated questioning by the defence did the modern court-appointed experts state that a suspect having teeth 41 and 31 labio-lingually related as the suspect is compatible with having a bitemark with corresponding marks oppositely related: This was explained by the properties of the skin. The expert-witnesses assisting the defense disagreed — claiming it to exclude Torgersen as the biter. The court-experts appealed to the effect of skin-properties when explaining the possibility of the opposite relationship, but did not appeal to the other mechanisms activated during the biting. The expert-witnesses for the defense did not comment at all about the effects of these mechanisms. Nor could they appeal to any published knowledge about such relationships as no studies existed by 2001. No studies had been performed by December 2008 either.

To pursue the illustration of the methodology and the model from the previous chapters I will assume that

- 5d1.** the expert used the instruments of  $BMI141, 31$  and  $BMI25, 6$  when classifying  $labio-lingual5, 6$  of the bitemark and  $labio-lingual41, 31$  of the biting-mechanism respectively;
- 5d2.** they reported the suspect's biting-mechanism to have profile  $BMI141, 31 = bmi141, 31_{sbm}$  and the bitemark to have profile  $BMI25, 6 = bmi25, 6_{cbm}$ ;
- 5d3.** the two profiles are the objects' true profiles (no false positives/negatives for these decisions). This assumption is done for simplifying purposes.
- 5d4.** the proportion of biting-mechanisms in the relevant population sharing the same profile as the suspect is 50% and the proportion with a different profile,  $\neg bmi141, 31$ , is 50%. This distribution is justified by the lack of information about this characteristic in the relevant population (biting-mechanisms in Oslo 1958).
- 5d5.** of all the biting-mechanisms which will cause  $bmi25, 6$ -profiled bitemarks 50% have profile  $bmi141, 31$  and 50% have a different profile,  $\neg bmi141, 31$ . The justification for this distribution is the inability to discriminate between the available expert-information about this relationship.

**5d6.** the expert's perceptions and observations of *labio-lingual 5,6* and *labio-lingual 41,31* under conditions similar to the Torgersen-case yields very poor diagnostic accuracy:

- via *labio-lingual 5,6* and *labio-lingual 41,31* alone, experts are able to identify the true biting-mechanism 50% of the times and true negative biting-mechanism 50% of the times.
- the expert thus has a false positive rate of 50% and a false negative rate of 50%.

This distribution is justified by the judgment that the current state of expert agreement and experience/knowledge about the relationship between *labio-lingual 5,6* and *labio-lingual 41,31* is poor — providing a discriminating power similar to that of tossing a coin.

**Assumption 5e. The relationship among the characteristics observed of the biting-mechanisms and among those observed of the bitemark** I will, finally, assume independence between *BMI1m*, *BMI1a*, *BMI142*, and *BMI141,31* and independence between *BMI2m*, *BMI2a*, *BMI24a*, and *BMI25,6*. The experts on the Torgersen-case did not comment on the issue of dependence/independence between the characteristic observed. And the literature on bitemark-analysis contains no published studies of the relationship between teeth-wear and kinds of teeth-rotation/positioning or any similar relationships relevant for forensic bitemark-analysis. I know of general odontological studies of such relationships concerning teeth, but chose not to review these as I would not be able to assess their relevance to bitemark-analysis. The bitemark-literature did not contain studies referring to these studies either. The question of dependency between characteristics seems not to be found relevant to bitemark-analysts — most likely because their current methodology does not induce this question. The profiling-instruments specified above may just as well be dependent — due to a common cause such as *kind of occlusion*, *jaw-size*, etc. and/or due to the mechanisms activated during the biting-process. It is impossible for me to opine on the nature of such dependencies as I am no odontologist. The only criterion for choosing independence is thus that it makes the analysis simpler. The consequence if I am wrong, which is a real possibility, is that the discriminating power is wrong. This, again, is not serious as long

the single aim is to illustrate the methodology and the model of the previous chapters.

### **Assumption 6. The profiling for diagnosing simultaneity**

In the Torgersen-case, according to the written reports, no expert or investigator profiled any items for determining the simultaneity between the bitemark and the crime act. The diagnosis about simultaneity is a necessary criterion for deciding about the relevance of the bitemark to the crime act. The investigators thus repeatedly decided, consciously or not, that the profiles, their relevance, and their similarity were sufficiently justified by expert-information. In order to proceed with the illustration of the methodology and the model I will have to assume that the expert used a given profiling instrument, *TI*, containing the characteristics relevant for determining simultaneity.

The kind of characteristics included in a *TI* will depend on how close in time he investigator needs "simultaneity" to mean. In one-offender bitemark-cases it is not difficult to imagine a situation in which a bitemark is made by one person minutes before yet unrelated to the crime act that in turn is caused by another person. If we stretch the simultaneity to mean one hour, this possibility becomes more than just speculation. The latter would be a relevant possibility in the Torgersen-case.

In the forensic literature on the question of the age or timing of skin-injuries, immunohistochemical markers have been identified which enable discrimination down to minutes. These markers are however not been validated for practical forensic case-work and there are yet no accuracy studies of diagnosis via these markers. Cruder histological markers, enabling discrimination between hours and days are better studied. So, if the investigator needs simultaneity to mean within an hour, the investigator must use case-specific non-medical kinds of information.

In the Torgersen-case four of the individual marks of the bitemark were agreed to have disrupted the epidermis and the dermis, which means that a certain force must be assumed to have been used. If the bitemark was made during an event unrelated to the crime event, this in turn means that the victim must have been involved in two violent interactions on the same day, the bitemark having been made consensually or not. This is possible — the victim may have been abnormally prone to abuse. The information available suggests that the victim in the Torgersen-case was not particularly prone to

abuse.

On the other hand it is of course possible that the bitemark occurred simultaneously with the crime event. The nature of the crime scene, with the clothes having been torn off the way it had, strongly suggesting a sexual attach, is information relevant to this possibility. Due to (a) the lack of both case-based and general information about the medical forensic markers for diagnosing simultaneity and (b) the lack of information about the victim's propensity for being abused I will assume the following scenario to be representative:

- 6a.** The investigator and the bitemark-expert or the forensic examiner used the instrument of  $TI$  — which involves both histological markers and non-expert circumstantial information — when classifying the bitemark and the control-injury;
- 6b.** They agreed to report the bitemark to have profile  $TI = ti_{cbm}$  and the control-injury to have profile  $TI = ti_{li}$ ;
- 6c.** I will assume for simplicity that these two profiles are the objects' true profiles (no false positives/negatives for these classification-decisions);
- 6d.** I will suggest that the probability that the victim had been exposed to two independent violent interactions on the same evening (that the bitemark and the control-injury are effects of different processes) is set at 0.05. The probability that they are the effect of the same mechanism is then 0.95. Again, my choice is motivated solely by the purpose of illustrating the methodology and the model and does not aspire to be a best estimate.
- 6e.** According to the epistemological norms I should further assume that the experts and the  $TI$ -instruments are not perfectly able to discriminate between the two possibilities. Having no other justification than the need to illustrate the methodology and the model of the previous chapters I will suggest that the decision-makers are able to detect 80% of the true simultaneous cases and 80% of the true not simultaneous cases. The risk that this estimate is wrong is real, but the consequences of being wrong are considered to be less serious given this purpose than if the purpose was to arrive at a best estimate. For the latter purpose I would have had to be much more careful and included far more relevant information.

**Assumption 7. The value of the possible consequences in the case.**

In any bitemark-case the possible consequences are of a kind and order similar to those specified in the previous chapter. The investigator can either decide  $a_1$ , that the bitemark-proposition is positively relevant to the indictment-proposition conditional on the profiles observed, and be either correct, contributing to convict a true offender, or wrong, contributing to convict a true innocent; or decide  $a_0$ , that the bitemark-proposition is negatively relevant to the indictment-proposition conditional on the profiles observed, and be either correct, contributing to acquit a true innocent, or wrong, contributing to acquit a true offender. In the previous chapter I suggested that the values associated with the possible consequences of the possible decisions in the crime investigator's bitemark-problem could be represented via *utility* and denoted as follows:

$(c_1 \text{ through } c_4) \sim c_k, k = \{1, 2, 3, 4\}$ ; Value associated with  $c_k \sim U(c_k)$ ,  $U(c_k) = (u_{c_1}, u_{c_2}, u_{c_3}, u_{c_4})$ ;  $c_1$  denoting an extreme consequence, the absolutely best;  $c_2$  denoting the consequence next most valued;  $c_3$  denoting the consequence next least valued; and  $c_4$  denoting an extreme consequence, the absolute worst.

The magnitude of the values, however, may depend on the legal injury under investigation: An injury involving the death of a physically weaker or dependent person in addition to sexual assault is more serious than that involving equally strong individuals and not resulting in death. In a case similar to the Torgersen-case, involving the death of a 16 years old girl and possibly sexual assault is undeniably serious. Should the distances between the possible losses be equal? Would the loss in value when moving from the consequence  $c_1$  ("contributing to convict a true guilty") to  $c_2$  ("contributing to acquit a true innocent") be felt equally serious to the losses of moving from  $c_2$  to  $c_3$  (contributing to acquit a true guilty") and from  $c_3$  to  $c_4$  ("contributing to convict true innocent")? I believe it would not: The loss involved moving from  $c_1$  to  $c_2$  would be small compared to that when moving from  $c_2$  to  $c_3$  and to that when moving from  $c_3$  to  $c_4$ , but the loss when moving from  $c_2$  to  $c_3$  should be larger than the loss involved when moving from  $c_3$  to  $c_4$ . I suggest and assume that the following distribution is a better model of the possible losses than that of equal losses:

$$u_{c_1} = 10; \quad u_{c_2} = 8; \quad u_{c_3} = 4; \quad u_{c_4} = 1.$$

### Assumption 8. The Bayesian Network given the above assumptions

The Bayesian network for the scenario conditional on the assumptions of 1 through 6 above is suggested to be as shown in figure 11.1.

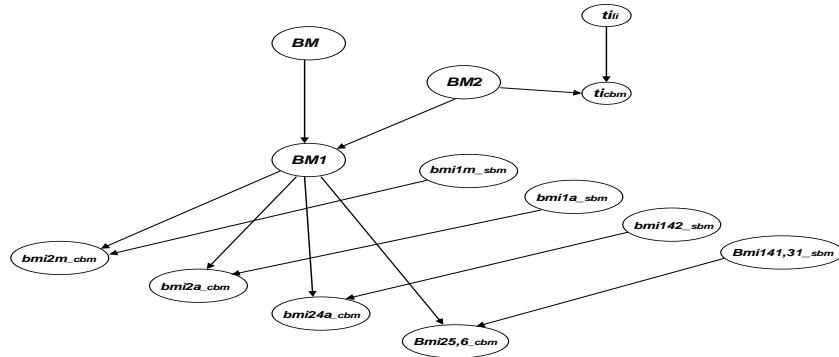


Figure 11.1: A Bayesian network for assessing the bitemark-proposition in the case approximating that of the Torgersen-case (the nodes hosts variables representing the same events as above, only that the suspect, bitemark, teeth/biting-mechanism etc. are particularized to a case representing  $K_0$ , the context-condition specified in the first section).

Denoting the pairs of characteristics by  $i, (i = m, a, (4a(42)), (5, 6(41.31)))$  The corresponding likelihood-ratio to this network is as follows:

$$LR = \frac{\left\{ \prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_1) \right\} [sim + \beta(1 - sim)] + \left\{ \prod \gamma_i \right\} [(1 - \beta)(1 - sim)]}{\left\{ \prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_0) \right\} [\beta(1 - sim)] + \left\{ \prod \gamma_i \right\} [sim + ((1 - \beta)(1 - sim))] } \quad (11.1)$$

The parameters which need to be assessed are then the following:

- $BM_1$  and  $BM_0$ : Whether the suspect or someone else made the bitemark simultaneously with the control-injury;
- $BM_1$  and  $BM_0$ : Whether the suspect or someone else' teeth/biting-mechanism is the causal object of the bitemark;
- $BM_2$  and  $BM_0$ : Whether the bitemark was made simultaneously or not with the control-injury.

The numerical specification of these parameters requires an assessment of the conditional and the unconditional probabilities. This is the topic of the next section.

## 11.2 The numerical specification of the conditional and the unconditional probabilities

### 11.2.1 The node hosting $BM_j$ : The prior probabilities that the suspect versus another person made the bitemark simultaneously with the legally relevant injury

What is the prior probability that the suspect made the bitemark simultaneously with the legally relevant injury? This uncertainty and its complement — the uncertainty about the possibility that another person made the bitemark simultaneously or not with the legally relevant injuries — must be assessed and suggested before the other conditional uncertainties can be assessed. This assessment is just a methodological answer to a basic epistemic need recognized by most epistemological theories: To assess the uncertainty of a particular event we need to identify the most appropriate or best *reference-class*, *reference-basis*, *reference-population*, or *collection of initially similar situations/individuals* by which to compare and assess whether the effect or value of the expert-information is large, small, or indifferent.

Just like the patients of a primary physician are unique individuals, so are the cases of the crime-investigator: An individual patient's symptoms or an individual case's traces may resemble those of other patients/cases, but the background-conditions will be different; two patients may complain about chest-pain, heart-problem may be abduced as a possible cause for both, but heart-problem will be much less likely for the physically active teenager than for the inactive but busy corporate manager — because heart-problems are much more frequent among inactive busy corporate managers than among physically active teenagers. The physician knows about these different base- or population-rates by his/her training, personal and others experience of patients, and scientific studies — so he/she will set the prior probabilities of

heart-problem differently for the two groups. This will be analogue to the situation of the crime-investigator: Two cases, both presenting a murdered and raped young female victim and an arrested individual male, will both have that the arrested male is abduced as a possible cause, but the prior probability that he is the cause will be different in the two cases due to case-particularities.

The finding of the most appropriate reference-basis is familiar to crime investigation and legal assessment of the relevance of evidence: The International Journal of Evidence and Proof, 2007;11:243-317 for example, contains a series of papers on the problem of reference-class in legal assessments of evidence. Some of the papers here even use the legal need to identify the best comparison-basis as an argument against formal approaches in the legal context — because formal approaches, it is claimed, will be biased towards classes for which knowledge already exists and preferably then in numerical form (Roberts 2007)! This must be a misunderstanding. The reference-class problem is central to *any* person needing to assess the value of something in a conditioned situation — and the more important it is to get that value right, the more important it is to get the reference-class right. The risk of choosing wrong/inappropriate reference-populations via formal methodologies is no greater or less than via informal methodologies as both is used for the purpose of relevant assessments.

In the Torgersen-case Torgersen was abduced as a possible cause due to initial information about the time and place of his arrest (and possibly his previous police-records). These characteristics made it physically possible that he could be the offender. But the written sources do not give any clues to how the investigator reasoned about the reference-class or base-rate for the initial probability that Torgersen was the cause of the injuries: If only presence in time and place were the initial characteristics then the number of other possible offenders would have been quite large considering the crime scene being in urban semi-residential area and it being a Friday night; but if one includes a police record containing a previous conviction of rape, the suspect-population becomes rather small. I am not certain whether the Norwegian legal system allows previous convictions to be relevant or not. In the following I will omit this characteristic, but I will in the next section illustrate how the value of the bitemark-evidence change when the reference-class change, when we include more relevant information, possibly in the form of previous convictions. The investigator of course reflected about other possible suspects as well as the base-rate, but neither the first nor the modern

investigators seems to think of the reference-populations as a *methodological* instrument by which to assess, express, and justify their conclusion about the strength of probability that Torgersen was the offender. Neither did the bitemark-experts on the Torgersen-case with respect to their diagnoses — and neither would any bitemark-expert according to the review of the analytical norms among bitemark-analysts in chapter 7. As said above, most epistemological theories and certainly Bayesian Theory recognize the need for reference-classes, and the  $BN_s$ -methodology of this dissertation requires the analyst to formulate and justify it explicitly.

To proceed I will therefore suggest a reference-population in terms of a prior probability of  $BM_1$  — i.e., the probability that the suspect is the one who bit simultaneously with the control-injury *after* the investigator has seen the crime scene and the victim and decided a possible time for the crime act ( $T = t_0$ ), but *before* the investigator has received any other information from experts or witnesses. According to the principle of innocence, the person arrested and suspected should, *before* any information is systematically assessed for relevance, be perceived to be neither more nor less a likely offender than any other person which could possibly have committed this crime. In our case and in the Torgersen-case, the suspect was arrested approximately at 00.58 am, 500m from the crime scene 30 minutes prior to the alarm went at the fire-department (received call 1.27am). The last certain observation of the victim was by a neighbor at the address of the crime scene at 11.00pm. The sources has no information on how the first investigator reasoned about the suspect-population, but say that it is not completely wrong to say that any person within 1 km of the crime scene in the time interval between 11.00 pm and 1.30am is a possible suspect. How many persons would this be? 2000? 20? Let us say that a reasonable estimate is 350 persons — assuming the offender to have been an adult but not older than 80 years. This figure must of course be justified in practice. Can the crime investigator limit more? The kind of circumstances and injuries of the crime scene may be reason for anticipating that the offender was an adult male (to be justified again). Say for my limited purpose of illustration that this leaves a suspect population of 100. In the last section I will study how a larger or smaller population affects the results. The point now is just to establish a *base-population* to which we may relate the expert-information on the bitemark. A suspect-population of 100 persons gives that the prior probability of the possibility that an identified suspected person is the cause,  $P(BM_1)$ , is 0.01 — since the suspect is one of these 100 persons. As there

are 99 other possible unidentified suspects, the probability that any of these is the cause,  $P(BM_0)$ , is 0.99.

### 11.2.2 The node hosting $BM2_j$ : The prior probabilities that the bitemark was made simultaneously or not with the control-injury

Above, degree of certainty about the event of  $BM2$ ,  $P(BM2_1)$ , was denoted by  $sim$ . Before any case-specific information is related systematically to the alternative possibilities the crime-investigator may suspect that the bitemark was made simultaneously with the lethal injuries — due to the site of the bitemark and the other characteristics suggesting a sexualized crime. A conservative estimate of the prior uncertainty about simultaneity is therefore to let it be just as probable as its opposite possibility:  $P(BM2_1) = sim = 0.5$  and  $(P(BM2_0) = 1 - sim = 0.5)$ .

How is this prior probability changed by the information on the histological markers and the case-specific non-medical information — when the bitemark and the control-injury has been profiled by the  $TI$ -instrument? I assumed in the previous section that the items' profiles were informed to be  $ti_{cbm}$  and  $ti_{li}$  (and without error). It was further assumed that similar  $TI$ -profiles may be observed even if the bitemark was caused during an event unrelated to the crime event: The probability of observing similar profiles when the bitemark was made some hours earlier during an irrelevant event was suggested to be 0.05; and the probability of observing similar profiles when the bitemark made during the crime event were suggested to be 0.95. It was further assumed that the investigator and the expert are able to detect 80% of the true simultaneous cases and 80% of the true non-simultaneous cases.

What would then be the posterior probability of  $sim$ , conditional on this expert-information? This question is suggested formally expressed and answered as follows:

$$P(BM2_1 \mid ti_{cbm}, ti_{li}) = \frac{P(ti_{cbm} \mid ti_{li}, BM2_1) \cdot P(BM2_1)}{P(ti_{cbm} \mid ti_{li}, BM2_1) \cdot P(BM2_1) + P(ti_{cbm} \mid ti_{li}, BM2_0) \cdot P(BM2_0)}.$$

We must now establish the likelihoods of each of the possible hypotheses about simultaneity.

**Node  $ti_{cbm}$ :**

There are basically two possibilities to assess: The experts have reported to have observed the two profiles, but what is the probability of this observation conditional on each of the two possible states of  $BM2_j$  —  $P(ti_{cbm} | ti_{li}, BM2_1)$  and  $P(ti_{cbm} | ti_{li}, BM2_0)$ ?

$P(ti_{cbm} | ti_{li}, BM2_1)$ : In the case the bitemark and the control-injury are simultaneous, then the probability of observing similar profiles is 0.95.

$P(ti_{cbm} | ti_{li}, BM2_0)$ : In this scenario the bitemark and the control-injury are not simultaneous — the probability of observing similar profiles is then 0.05.

The local value of expert-information on the  $TI$ -marker for the two samples is  $V_{BM2_j} = 0.95/0.05$  — or, in odds, the value is 19:1 in favor of the suspected hypothesis.

Given the conditional independence between the  $BM_j$  and the  $BM2_j$  we may proceed to update the uncertainty of the latter now: How much has this information changed the prior probability of the suspected hypothesis? If my suggested prior probability of 0.5 is reasonable, the posterior probability of  $BM2_1$  may be calculated as follows:

$$\begin{aligned} P(BM2_1 | ti_{cbm}, ti_{li}) &= \frac{P(ti_{cbm} | ti_{li}, BM2_1)P(BM2_1)}{P(ti_{cbm} | ti_{li}, BM2_1)P(BM2_1) + P(ti_{cbm} | ti_{li}, BM2_0)P(BM2_0)} \\ &= \frac{0.95 \cdot 0.5}{(0.95 \cdot 0.5) + (0.05 \cdot 0.5)} = 0.95. \end{aligned}$$

The posterior probability of the alternative hypothesis,  $P(BM2_0)$  is then  $1 - 0.95 = 0.05$ .

The experts agreed that the bite-mark and the control-injury in this case are simultaneous and this must be accounted for: What is the probability that the experts are correct when they report that the two injuries occurred simultaneously? Denoting the expert-report by  $W_{sim}$  and recalling assuming them to be accredited at 80% accuracy,

$$P(BM2_1 | W_{sim}) = \frac{0.95 \cdot 0.8}{(0.95 \cdot 0.8) + (0.05 \cdot 0.2)} = 0.987.$$

We may let these posterior probabilities represent  $sim$  and  $1 - sim$  respectively:  $sim = 0.987$  and  $1 - sim = 0.013$ .

Before we can insert these results into the likelihood-ratio suggested for the investigator's bitemark-problem we must attend to the other nodes in the network.

### 11.2.3 The node hosting $BM1_j$

The probability of the possible events of  $BM1$  is, according to my suggested model, conditional on  $BM_j$  and  $BM2_j$ . In the previous chapter I explained that the probabilities of  $BM1_1$  and  $BM0$  conditional on  $BM2_1$  and  $BM1$  before any information is received about the relevant profiles of the bitemark and the suspect's biting-mechanism will logically be 1 and 0 respectively. The probabilities of the other possibilities are derived the same way and are tabulated in table 1:

$BM1$				$BM0$			
$BM2_1$		$BM2_0$		$BM2_1$		$BM2_0$	
$BM1_1$	$BM1_0$	$BM1_1$	$BM1_0$	$BM1_1$	$BM1_0$	$BM1_1$	$BM1_0$
1	0	1	0	0	1	$\beta$	$1 - \beta$

Table 11.1: The probabilities of  $BM1_j$  conditional on  $BM2_j$  and  $BM_j$ .

### 11.2.4 The node hosting $bmi2m_{cbm}$ :

This is the event that the bitemark is reported by the bitemark-experts to have the profile  $bmi2m_{cbm}$  on the *rotation/position*-index,  $BMI2m$ . This report was assumed for simplifying reasons to be a true positive. The experts were further assumed to have recommended (a) that the suspect's biting-mechanism had the profile of  $bmi1m_{sbm}$  (also assumed to be a true positive) and (b) that the two profiles were compatible with each other. This is part of the bitemark-experts' justification why they recommend the suspect's biting-mechanism to be the most likely causal teeth/biting-mechanism.

In section one of this chapter I assumed the possibility that biting-mechanisms could be classified via the  $BMI1m$ -index to be either a  $bmi1m$  or a  $\neg bmi1m$ , and that  $bmi1m$  was shared by 40% of the relevant population and  $\neg bmi1m$  by 60%. Both these kinds of biting-mechanisms can produce bitemarks (of the subgroup specified in the previous chapter) on human skin which either may be classified as  $bmi2m$  or  $\neg bmi2m$  via a cor-

responding  $BMI2m$ -index. The following general possible joint distribution of biting-mechanisms and bitemarks was suggested and assumed:

	$bmi1m$	$\neg bmi1m$	
$bmi2m$	$0.8 \cdot 0.4 = 0.32$	$0.2 \cdot 0.6 = 0.12$	0.44
$\neg bmi2m$	$0.2 \cdot 0.4 = 0.08$	$0.8 \cdot 0.6 = 0.48$	0.56
	0.4	0.6	1.00

Table 11.2: Suggested distribution of biting-mechanisms and bitemarks on human skin with respect to possible states on *rotation/position*-indexes,  $BMI1m$  and  $BMI2m$ .

There are basically two possibilities to assess: The expert reported that the two observed profiles were compatible, but what is the probability of this observation conditional on each of the two possible states of  $BMI1$  —  $P(bmi2m_{cbm} | cbm1m_{sbm}, BMI1_1)$  and  $P(bmi2m_{cbm} | cbm1m_{sbm}, BMI1_0)$ ?

$$\underline{P(bmi2m_{cbm} | bmi1m_{sbm}, BMI1_1)}$$

In this scenario the suspect is the only individual involved and his biting-mechanism is the true causal object of the bitemark. When the expert is perfect in the profiling of each of the two forensic objects and it is certain that the suspect is the only individual involved, the likelihood that the suspect's biting-mechanism, having profile  $bmi1m$ , made this bitemark with its  $bmi2m$ -profile is:

$$\begin{aligned} P(bmi2m_{cbm} | bmi1m_{sbm}) &= \\ \frac{P(bmi1m_{sbm} | bmi2m_{cbm})P(bmi2m_{cbm})}{P(bmi1m_{sbm} | bmi2m_{cbm})P(bmi2m_{cbm}) + P(bmi1m_{sbm} | \neg bmi2m_{cbm})P(\neg bmi2m_{cbm})} &= \\ \frac{0.8 \cdot 0.4}{0.8 \cdot 0.4 + 0.2 \cdot 0.4} &= 0.8 \end{aligned}$$

This may then be used as the value of the first term in the nominator of the overall likelihood ratio  $V_{BM}$ .

$$\underline{P(bmi2m_{cbm} | (bmi1m_{\neg sbm} \cup \neg bmi1m_{\neg sbm}), BMI1_0)}$$

In this scenario someone else's biting-mechanism — with profile  $bmi1m_{\neg sbm}$  or profile  $\neg bmi1m_{\neg sbm}$  — is the relevant reference-basis:

$$P(bmi2m_{cbm} | bmi1m_{\neg sbm} \cup \neg bmi1m_{\neg sbm}) =$$

$$\begin{aligned}
& \frac{P(bmi1m_{\neg sbm} \cup \neg bmi1m_{\neg sbm}) | bmi2m_{cbm}) P(bmi2m_{cbm})}{P(bmi1m_{\neg sbm} \cup \neg bmi1m_{\neg sbm}) | bmi2m_{cbm}) P(bmi2m_{cbm})} = \\
& + P(bmi1m_{\neg sbm} \cup \neg bmi1m_{\neg sbm}) | \neg bmi2m_{cbm}) P(\neg bmi2m_{cbm}) \\
& \frac{0.44}{1} = 0.44
\end{aligned}$$

This is also what is sometimes called the "random match"-probability — the probability of randomly finding a biting-mechanism which could make a  $bmi2m$ -profiled bitemark under circumstances similar to our case. Its size is very large compared to that in DNA-cases. This is because almost half of the relevant population of biting-mechanisms could have made a bitemark with the observed profile: The profile is simply not very rare and therefore has not much discriminatory power. This "random match" probability was in the previous chapter denoted by  $\gamma$ . The probability of observing the *rotation/position*-profile of the bitemark when someone else's biting-mechanism is the cause of the bitemark will be denoted by  $\gamma_m$ :  $\gamma_m = 0.44$ .

I also justified and suggested that the expert's ability to diagnose correctly when using the *rotation/position*-characteristic alone could be estimated to be 80% true positives and 20% false positives. In a practical case, however, I find it difficult to justify that the expert would first diagnose according to *rotation/position* and then move on to diagnose according to another characteristic independently of the previous conclusion. In practical cases there is, in other words, a distinct possibility that the diagnoses via the chosen characteristics are dependent on each other. As I find this possibility more likely than that of independence I will postpone the assessment of the joint expert-accuracy until the end of this section.

### 11.2.5 Node $bmi2a_{cbm}$

This is the event that the bitemark is reported by the bitemark-experts to have the profile  $bmi2a_{cbm}$  on the *kind and degree of wear-index*,  $BMI2a$ . This report was assumed for simplifying reasons to be a true positive. The experts was further assumed to have recommended (a) that the suspect's biting-mechanism had the profile of  $bmi1a_{sbm}$  (also assumed to be a true positive) and (b) that the two profiles are compatible with each other and is part of the bitemark-experts' justification why they recommend the suspect's biting-mechanism to be the most likely causal biting-mechanism — that  $BM1_1$  is more likely than  $BM1_0$ .

In section one of this chapter I assumed the possibility that biting- mech-

anisms could be classified via the  $BMI1a$ -index to be either a  $bmi1a$  or a  $\neg bmi1a$ , and that  $bmi1a$  was shared by 5% of the relevant population and  $\neg bmi1a$  by 95%. Both these kinds of biting-mechanisms can produce bitemarks (of the subgroup specified in the previous chapter) on human skin which either may be classified as  $bmi2a$  or  $\neg bmi2a$  via a corresponding  $BMI2a$ -index. The following general possible distribution of biting-mechanisms and bitemarks was suggested and assumed:

	$bmi1a$	$\neg bmi1a$	
$bmi2a$	$0.8 \cdot 0.05 = 0.04$	$0.2 \cdot 0.95 = 0.19$	0.23
$\neg bmi2a$	$0.2 \cdot 0.05 = 0.01$	$0.8 \cdot 0.95 = 0.76$	0.77
	0.05	0.95	1.00

Table 11.3: Suggested distribution of teeth/biting-mechanisms and bitemarks on human skin with respect to possible states on wear-indexes,  $BMI1a$  and  $BMI2a$ .

Again there are basically two possibilities to assess: The experts have reported to have observed the two profiles, but what is the probability of this observation conditional on each of the two possible states of  $BMI_j$  —  $P(bmi2a_{cbm} | bmi1a_{sbm}, BM1_1)$  and  $P(bmi2a_{cbm} | (bmi1a_{\neg sbm} \cup \neg bmi1a_{\neg sbm}), BM1_0)$ ?

$$\underline{P(bmi2a_{cbm} | bmi1a_{sbm}, BM1_1)}$$

The reasoning will be analogue to that of the previous characteristic:

$$\begin{aligned} P(bmi2a_{cbm} | bmi1a_{sbm}) &= \frac{P(bmi1a_{sbm} | bmi2a_{cbm})P(bmi2a_{cbm})}{P(bmi1a_{sbm})} = \\ &= \frac{0.8 \cdot 0.05}{0.8 \cdot 0.05 + 0.2 \cdot 0.05} = 0.8 \end{aligned}$$

This may then be used as the value of the second term in the nominator of the overall likelihood ratio  $V_{BM}$ .

$$\underline{P(bmi2a_{cbm} | (bmi1a_{\neg sbm} \cup \neg bmi1a_{\neg sbm}), BM1_0)}$$

In this scenario someone else's biting-mechanism — with profile  $bmi1a_{\neg sbm}$  or profile  $\neg bmi1a_{\neg sbm}$  — is the reference-group:

$$P(bmi2a_{\neg cbm} | (bmi1a_{\neg sbm} \cup \neg bmi1a_{\neg sbm}), BM1_0) = 0.23$$

This is then the random "match"-probability via wear alone.

The size of this probability is still quite large compared to that in DNA-cases, but it is smaller than via *rotation/position*. The suggested low proportion of people with biting-mechanism having a kind and degree of wear similar to the suspect's mechanism enables a better discriminatory power via wear than via *rotation/position* — *if*, that is, the expert is good at not only detecting the symptoms, but also at differentiating among such symptoms — recognizing this particular wear from other kinds and degrees of wear (above I justified there to be reason not to expect high accuracy via this characteristic).

The probability of observing the wear-profile of the bitemark when someone else's teeth/biting-mechanism is the cause of the bitemark will be denoted by  $\gamma_a$ :  $\gamma_a = 0.23$

### 11.2.6 The node hosting $bmi24a_{cbm}$

This is the event that the bitemark is reported by the bitemark-experts to have the state  $bmi24a_{cbm}$  on the *existence4a*-characteristic,  $BMI24a$  (the scale for determining the existence of a sub-mark in the position between sub-marks nr. 4 and 5). This report was assumed for simplifying reasons to be a true positive. The expert was further assumed to have recommended (a) that the suspect's biting-mechanism was a  $bmi142_{sbm}$  (tooth 42 exists and its height is lower than adjacent teeth) (also assumed to be a true positive) and (b) that the two states were compatible with each other. This is the third piece of information used by the bitemark-experts to justify why they recommend the suspect's biting-mechanism to be the most likely causal biting-mechanism.

Above I assumed  $BMI42 = bmi142$  was shared by 50% of the relevant population and  $\neg bmi142$  by 50%. Both these kinds of biting-mechanisms can produce bitemarks being classified as  $bmi24a$  or  $\neg bmi2m$  ("No existence of a sub-mark in the position between sub-marks 4 and 5"). The following general possible distribution of biting-mechanisms and bitemarks was suggested and assumed:

Again two possibilities must be assessed: The expert reported that the two observed characteristics were compatible, but what is the probability of this observation conditional on each of the two possible states of  $BM1_1$  —  $P(bmi24a_{cbm} \mid cbm142_{sbm}, BM1_1)$  and  $P(bmi24a_{cbm} \mid cbm142_{sbm}, BM1_0)$ ?

	$bmi142$	$\neg bmi142$	
$bmi24a$	$0.50 \cdot 0.50 = 0.25$	$0.50 \cdot 0.50 = 0.25$	0.50
$\neg bmi24a$	$0.50 \cdot 0.50 = 0.25$	$0.50 \cdot 0.50 = 0.25$	0.50
	0.50	0.50	1.00

Table 11.4: Suggested distribution of biting-mechanisms and bitemarks on human skin with respect to possible states on 4a(42)-characteristics,  $BMI142$  and  $BMI24a$ .

$$P(bmi24a_{cbm} \mid bmi142_{sbm}, BM1_1)$$

Again, In this scenario the suspect is the only individual involved and his biting-mechanism is the true causal object of the bitemark:

$$P(bmi24a_{cbm} \mid bmi142_{sbm}, BM1_1) = 0.5.$$

This value may then be used for the third term in the nominator of the overall likelihood ratio  $V_{BM}$ .

$$P(bmi24a_{cbm} \mid (bmi142_{\neg sbm} \cup \neg bmi142_{\neg sbm}), BM1_0)$$

Again, in this scenario someone else's biting-mechanism — with state  $bmi142_{\neg sbm}$  or  $\neg bmi142_{\neg sbm}$  — is the reference group:

$$P(bmi24a_{\neg cbm} \mid (bmi142_{\neg sbm} \cup \neg bmi142_{\neg sbm}), BM1_0) = 0.50$$

This is then the "random match"-probability via this characteristic. Its size is large due to half of the relevant population of biting-mechanisms being able to make a bitemark with the observed profile. The discriminatory power achieved via this characteristic was in the previous section justified to be limited — the court-experts in the Torgersen-case claimed a relatively small tooth 42 could make a bitemark without a detectable imprint from this tooth and the defense-experts claimed it would and that a space in the bitemark implies the absence of tooth 42. And no study exists on the effects of the visco-elasticity of the skin and or the mobility of teeth. This is the reason why I suggested that the discriminatory power of this characteristic should be considered small.

The probability of observing a bitemark with a potential mark 4a when someone else's biting-mechanism is the cause of the bitemark will be denoted by  $\gamma_{4a}$ :  $\gamma_{4a} = 0.50$ .

### 11.2.7 The node hosting $bmi25, 6_{cbm}$

This is the event that the bitemark is reported by the bitemark-expert to have the state  $bmi25, 6_{cbm}$  on the  $5,6(41,31)$ -characteristic,  $BMI25, 6$  (a scale for determining the relative labio-lingual positioning between the submarks 5 and 6) ( report assumed to be true positive). The experts were further assumed to have recommended (a) that the suspect's biting-mechanism was a  $bmi141, 31_{sbm}$  (the relative labio-lingual positioning between the teeth 41 and 31) (also assumed to be true positive) and (b) that the two states were compatible with each other. This is part of the bitemark-expert's justification why they recommend the suspect's biting-mechanism to be the most likely causal biting-mechanism — that  $BM1_1$  is more likely than  $BM1_0$ .

Above I assumed  $BMI141, 31 = bmi141, 31$  was shared by 50% of the relevant population and  $\neg bmi141, 31$  by 50%. Both these kinds of biting-mechanisms can produce bitemarks being classified as either  $bmi25, 6$  or  $\neg bmi25, 6$ . The following general possible distribution of biting-mechanisms and bitemarks was suggested and assumed:

	$bmi141, 31$	$\neg bmi141, 31$	
$bmi25, 6$	$0.50 \cdot 0.50 = 0.25$	$0.50 \cdot 0.50 = 0.25$	0.50
$\neg bmi25, 6$	$0.50 \cdot 0.50 = 0.25$	$0.50 \cdot 0.50 = 0.25$	0.50
	0.50	0.50	1.00

Table 11.5: Suggested distribution of biting-mechanisms and bitemarks on human skin with respect to possible states on  $5,6(41,31)$ -characteristics,  $BMI141, 31$  and  $BMI25, 6$ .

The expert reported that the two observed characteristics were compatible, but what is the probability of this observation conditional on each of the two possible states of  $BM1_1$  —  $P(bmi25, 6_{cbm} \mid cbm141, 31_{sbm}, BM1_1)$  and  $P(bmi25, 6_{cbm} \mid cbm141, 31_{sbm}, BM1_0)$ ?

$$\underline{P(bmi25, 6_{cbm} \mid bmi141, 31_{sbm}, BM1_1)}$$

The suspect is the only individual involved and his biting-mechanism is the true causal object of the bitemark:

$$P(bmi25, 6_{cbm} \mid bmi141, 31_{sbm}, BM1_1) = 0.50$$

This value may then be used for the fourth term in the nominator of the overall likelihood ratio  $V_{BM}$ .

$$P(bmi25, 6_{cbm} \mid (bmi141, 31_{\neg sbm} \cup \neg bmi141, 31_{\neg sbm}), BM1_0)$$

Here someone else's biting-mechanism — with state  $bmi141, 31_{\neg sbm}$  or profile  $\neg bmi141, 31_{\neg sbm}$  — is the reference-basis:

$$P(bmi25, 6_{\neg cbm} \mid (bmi141, 31_{\neg sbm} \cup \neg bmi141, 31_{\neg sbm}), BM1_0) = 0.50$$

This is then the "random match"-probability via this characteristic. The reason for its size is as for the previous characteristic. And the discriminatory power achieved via this characteristic must be expected to be small for the same reasons as for the previous characteristic.

The probability of observing a bitemark with a potential mark 4a when someone else's biting-mechanism is the cause of the bitemark will be denoted by  $\gamma_{5,6(41,31)}$ :  $\gamma_{5,6(41,31)} = 0.50$ .

### 11.2.8 Accounting for variance introduced by the expert.

In practical case-work one should account for the error and variation introduced by having a particular expert or experts performing the classifications/profiling of the forensic objects and the diagnoses. This expert(s) is also the one providing opinion about the appropriate base-rates for the diagnoses — which thus also may be more or less accurate. In forensic genetics the experts have access to both evidence-based knowledge as well as solid expert-consensus concerning the uncertainties involved for the three decision-tasks above — the particular geneticist involved on a given case may be expected to adhere to existing guidelines for the different scenarios that arise in particular cases. This cannot be expected in bitemark-cases given the current state of knowledge about bitemarks and expert-consensus on relevant concepts and markers. One may not even expect that the individual expert follows the guideline offered by the American Board of Forensic Odontology, the one organization otherwise recognized as an authority in the community of bitemark-experts.

How should one then account for the variation introduced by individual experts? Starting with the diagnostic decisions, I noted above the question about the diagnostic accuracy of a bitemark-expert using the four diagnostic instruments above. Given the existing level of development with respect to the diagnostic instruments of bitemark-analyses I found it difficult to justify

independence between the expert's conclusions on each: The reasoning and concluding on each is, I suggested, more likely dependent on each other. The particular accuracies were suggested to be as follows:

**Via rotation/position** :  $P(W_{BM1_1} | BM1_1) = 0.80$

**Via wear** :  $P(W_{BM1_1} | BM1_1) = 0.60$

**Via existence4a(42)** :  $P(W_{BM1_1} | BM1_1) = 0.50$

**Via labio-lingual5,6(41,31)** :  $P(W_{BM1_1} | BM1_1) = 0.50$

**Via expert-markers and case-markers** :  $P(W_{BM2_1} | BM2_1) = 0.80$

But how would the relationship be if contingent on each other? I find it difficult to justify one particular relationship. For illustrative purposes I will therefore simply assume that when all and only the four profiling-instruments are used for diagnosing *BM1* in our particular case, the expert is able to detect 70% of the true causal/non-causal biting-mechanisms:

$$P(W_{BM1_1} | BM1_1) = 0.70.$$

and

$$P(W_{BM1_1} | BM1_0) = 0.30.$$

The only justification I have is that this is the accuracy achieved in the one existing most relevant study on accuracy —Whittaker et al. (1998): In this study, real cases were diagnosed and no specified set of characteristic were required. The diagnosis concerned, however, only whether the bitemark was from an adult or child's biting-mechanism. In the less relevant studies (due to poor methodology or highly stylized biting-situations) the accuracies were slightly higher. An accuracy of 0.7 may thus be too high or too low. But it will have to do until further studies about the accuracy of bitemark-experts have been performed — and it will do for the purpose of this chapter and dissertation.

The next possible source of variation stems from the profiling-operations: just as the decision about the most likely causal biting-mechanism may be wrong, so may the profile ascribed to the forensic object. Above I assumed that the states ascribed to both the bitemark and the biting-mechanisms on their respective four diagnostic instruments were true positives. This may

not be expected in actual decisions. It is however difficult to justify any given value for a given expert — but I do suspect that the risks of false positives for the states of the bitemark should be expected to be larger than those of the biting-mechanism. Again, the lack of information due to the state of consensus about concepts and characteristics and the state of knowledge about bitemark-production makes the choice of distribution difficult. For the purpose of this chapter and dissertation, while awaiting further information I will continue with the assumption that the profiling of the forensic objects is perfectly reliable.

The last source of variation is then the case-expert's recommended reference-groups for the diagnoses. In the previous section I justified the distributions of the characteristics via my own opinion about what could be agreed to be the proportion of the population having *rotation/position* being *regular* and *kind and degree of wear* being *rare*. I suggested 40% and 5% respectively. But particularly the former could also be as large as 70% — that would no raise any eyebrow if the population concerned was a modern European population with its current state of dental health-care — almost all may have regular teeth today. In Oslo in 1958 — the population relevant for our bitemark-case — would be different with a smaller proportion having regular teeth. The point is that as long as few studies exist to support the expert-opinion concerning the distribution of the characteristics chosen to be observed the size of the likelihood ratio will dependent on the expert's accuracy in a more substantive way than is the case in forensic genetics.

How should this accuracy be estimated? What makes a bitemark-expert good or poor with respect to assessing proportions of a population having this or that characteristic? I suggest using solid training in odontology and forensic odontology, continual practical experience with biting-mechanism for health-purposes, and a serious interest in biting-mechanisms, bitemarks, and bitemark-production as relevant markers (bitemark-diagnostic experience was not relevant in three of the five accuracy studies which exist). If the expert is one with these qualities I suggest it to be reasonable to expect a sensitivity of above 60% but less than 90%. I will simply use 90% for both sensitivity and specificity, assuming the expert in our case to be among the more reliable:  $P(W_{\prod \gamma_i} | \prod \gamma_i) = 0.90$ . and  $P(W_{\prod \gamma_i} | \neg(\prod \gamma_i)) = 0.10$ .

Table three lists the unconditional and the conditional probabilities assigned to the nodes.

Prior probability of $BM_1$		0.01
Prior probability of $BM_0$		0.99
Posterior probability of $BM_{21}$	$P(BM_{21}   t_{cbm}, t_{li}) = sim$	0.99
Posterior probability of $BM_{20}$	$P(BM_{20}   t_{cbm}, t_{li}) = 1 - sim$	0.01
Conditional probability of $BM_{11}$	$P(BM_{11}   BM_{21}, BM_1)$	1.00
Conditional probability of $BM_{10}$	$P(BM_{10}   BM_{21}, BM_1)$	0.00
Likelihood of $BM_{11}$ (given rotation/position)	$P(bmi2m_{cbm}   bmi1m_{sbm}, BM_{11})$	0.80
Likelihood of $BM_{11}$ (given kind and degree of wear)	$P(bmi2a_{cbm}   bmi1a_{sbm}, BM_{11})$	0.80
Likelihood of $BM_{11}$ (existence4a(42))	$P(bmi24a_{cbm}   bmi142_{sbm}, BM_{11})$	0.50
Likelihood of $BM_{11}$ (labio-lingual5,6(41,31))	$P(bmi25,6_{cbm}   bmi141,31_{sbm}, BM_{11})$	0.50
”Random match” probability (rotation/position)	$P(bmi2m_{cbm}   (bmi1m_{-sbm} \cup \neg bmi1m_{-sbm}), BM_{10}) = \gamma_m$	0.44
”Random match” probability (wear)	$P(bmi2a_{cbm}   (bmi1a_{-sbm} \cup \neg bmi1a_{-sbm}), BM_{10}) = \gamma_a$	0.23
”Random match” probability (existence 4a(42))	$P(bmi24a_{cbm}   (bmi142_{-sbm} \cup \neg bmi142_{-sbm}), BM_{10}) = \gamma_{4a(42)}$	0.50
”Random match” probability (labio-lingual5,6(41,31))	$P(bmi25,6_{cbm}   (bmi141,31_{-sbm} \cup \neg bmi141,31_{-sbm}), BM_{10}) = \gamma_{5,6(41,31)}$	0.50
Diagnostic accuracy	$P(BM_{11}   W_{BM_{11}})$	0.70
Diagnostic accuracy	$P(W_{\prod \gamma_i}   \prod \gamma_i)$	0.90

Table 11.6: Unconditional and conditional probabilities assigned to the nodes of the bitemark-network.

### 11.3 The likelihood-ratio and the posterior odds on $BM_j$

The likelihood-ratio of  $BM_j$ ,  $V_{BM_j}$ , which was derived in the previous chapter and further specified to contain four independent expert-markers in the first section of this chapter, may now be used when the crime investigator in a bitemark-case approximately similar to the Torgersen-case is to assess the value of the expert-information with respect to the two diagnosis-conclusions recommended to the investigator.

Recall that the likelihood ratio for our problem was as follows (the pairs of characteristics being denoted by  $i$ ,  $(i = m, a, (4a(42)), (5, 6(41.31)))$ ):

$$LR = \frac{\left\{ \prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_1) \right\} [sim + \beta(1 - sim)] + \left\{ \prod \gamma_i \right\} [(1 - \beta)(1 - sim)]}{\left\{ \prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_1) \right\} [\beta(1 - sim)] + \left\{ \prod \gamma_i \right\} [sim + ((1 - \beta)(1 - sim))]} \quad (11.2)$$

I need to include the accuracies of the expert with respect to the diagnosis concerning the causal biting-mechanism and the population distribution of the characteristics, but I will make a simplifying assumption first: I will let  $\beta$  be 0;  $\beta$  represents the probability that the suspect made the bitemark during an event irrelevant to the legal injuries when he/she is also not the offender of these. Its complement represents the probability that someone else made the bitemark during an irrelevant event — these either being or not being the cause of the legally relevant injuries. Assuming a  $\beta$  of 0 or very small is to say that the population of biters (irrespective of the crime-case) is large. This is difficult to justify, but it is of no effect to the final  $LR$ . The  $LR$  under this assumption is:

$$LR = \frac{\left\{ \prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_1) \right\} sim + \left\{ \prod \gamma_i \right\} (1 - sim)}{\left\{ \prod \gamma_i \right\}}, \quad (11.3)$$

or

$$LR = \frac{\left\{ \prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_1) \right\} sim}{\left\{ \prod \gamma_i \right\}} + (1 - sim). \quad (11.4)$$

Now I may include the expert-accuracies:

$$LR = \frac{\{\prod P(bmi2i_{cbm} | bmi1i_{sbm}, BM1_1)\} P(W_{BM1_1} | BM1_1) sim}{\{\prod \gamma_i\} P(W_{\prod \gamma_i} | \prod \gamma_i)} + (1 - sim). \quad (11.5)$$

$$= \frac{0.80 \cdot 0.80 \cdot 0.50 \cdot 0.50 \cdot 0.70 \cdot 0.987}{0.44 \cdot 0.23 \cdot 0.50 \cdot 0.50 \cdot 0.90} + (0.013) = \frac{0.111}{0.0228} = 4.87$$

According to this ratio (and the assumptions about independent characteristics) it is 4.87 times more probable to observe this profiled bitemark under  $BM_1$  — i.e., if it were true that the suspect's  $bmi1$ -profiled biting-mechanism made the bitemark at the specified time-interval — than under  $BM_0$  — i.e., if it were true that someone else made the bitemark. This signifies that the expert-information on the forensic items makes a small, but positive difference — favoring  $BM_1$  over  $BM_0$ . I will return to discuss the crime investigative significance of this ratio in the next section. I must first consider the posterior posterior odds on  $BM_1$  conditional on this information.

The posterior odds on  $BM_1$  need to exceed 1 for the bitemark-position to be positively relevant to the indictment-proposition. I suggested above that the prior odds on  $BM_1$  to be 0.01 (to simplify expressions I will substitute  $LR$  by  $V_{BM_j}$  to signify that the  $LR$  may be interpreted as the value of the expert information):

$$\begin{aligned} \frac{P(BM_1 | V_{BM_j})}{P(BM_0 | V_{BM_j})} &= V_{BM_j} \frac{P(BM_1)}{P(BM_0)} \\ &= \frac{0.111}{0.0228} \frac{0.01}{0.99} \\ &= \frac{0.00111}{0.02257}. \end{aligned}$$

The posterior odds under the suggested prior odds are not greater than 1. As some may find it easier to relate to probabilities rather than odds:

$$P(BM_1 | V_{BM_j}) = \frac{P(V_{BM_j} | BM_1)P(BM_1)}{P(V_{BM_j} | BM_1)P(BM_1) + P(V_{BM_j} | BM_0)P(BM_0)}$$

$$= \frac{0.0011}{(0.0011 + 0.02257)} = 0.0469.$$

The posterior probability that the identified suspect made the bitemark simultaneously with the legally relevant injury conditional on the expert-information is 0.0469 — and the probability that someone else made the bitemark is the complement:

$$P(BM_0) = 1 - 0.042 = 0.9531.$$

Under the assumptions I made about the distributions of the characteristics I chose to include, the forensic evidence can thus be said to be positively relevant to the bitemark-proposition: It reduces the uncertainty from 0.01 to 0.0469 — when no other information relevant to the case is accounted for. A likelihood ratio of 4.87 is greater than one — which means that the expert-information is positively relevant, it does make a difference. In principle, at least, it is possible to say that this is evidence favoring the bitemark-proposition. But should the investigator recommend the bitemark-proposition to the prosecutor? Recalling the Norwegian Board of Forensic Medicine's statement about the practice in Scandinavian forensic genetics, in paternity cases, one is only allowed to speak with weight ("it is very likely") that a given man is the father of a child if the likelihood ratio exceeds 19 (or 95%) (The Norwegian Board of Forensic Medicine 2001:2). A ratio of 4.87, according to this standard, could thus not be recommended to be very likely, but something less.

Instead of comparing to the DNA-situation the investigator could ask about the risk posed to the aims and the values of the decision. The expert-information is positively relevant to the bitemark-proposition, but the investigator could either (1) recommend the information as positively relevant and be correct — thereby convicting the true offender (the best) — or be wrong — thereby convicting an innocent (the worst); or (2) recommend the information as negatively relevant and be correct — thereby acquitting the true innocent (the next best) — or be wrong — thereby acquitting the true guilty (the next worst). To assess the risk to aims and values and to evidence-base the decision the investigator could perform a utility-assessment:

Recall from the previous chapter that the crime investigator can decide  $a_1$ , positive relevance, if and only if

$$\bar{u}(a_1 \mid BM_1) > \bar{u}(a_0 \mid BM_j),$$

where

$$\bar{u}(a_i \mid BM_j) = \sum u(c_k) P(BM_j \mid a_i, V_{BM_j}, K_0)$$

$u(c_k)$  being the value attached to the consequence foreseen if deciding "positive relevance" when  $BM_j$  occurs and  $P(BM_j \mid a_i, V_{BM_j}, K_0)$  is the degree of belief in the occurrence of  $BM_j$  conditional on the event of deciding "positive relevance" while having the profiles observed of the forensic items.

$$\bar{u}(a_1 \mid BM_j) = u_{c_1} P(BM_1) + u_{c_4} P(BM_0) = (10 \cdot 0.042) + (1 \cdot 0.958) = 1.558$$

$$\bar{u}(a_0 \mid BM_j) = u_{c_3} P(BM_1) + u_{c_2} P(BM_0) = (4 \cdot 0.06) + (8 \cdot 0.94) = 7.832$$

According to the principle of maximizing expected utility the crime investigator should choose to decide "negative relevance". This means that the investigator should recommend the prosecutor to not construct and argue any separate bitemark-means of evidence —because the risk of being wrong, i.e. the risk of thereby contributing to convict a true innocent, is too high.

## 11.4 The effect of different reference-classes

In the above case I suggested prior odds on  $BM_1$  to be 0.01/0.99 — as I suggested there to have been 100 persons with the same initial characteristics (being within 1km radius of the crime scene between 11.00pm and 1.30am) as the suspect. This number of possible suspects may have been too low or too high — i.e., this reference-class may be inappropriate.

If we increase the size of the suspect population, then the utility of the option of recommending positive relevance will only decrease. But what if the population is smaller than 100 possible suspects — perhaps 50 or less, say 10? This will happen when other relevant information is accounted for. The likelihood-ratio will not change with the changing prior odds and neither will the risks of false positives. But the utility of the option of recommending "positive relevance" will with fewer suspects sooner or later become larger

Prior odds $\frac{P(BM_1 K_0)}{P(BM_0 K_0)}$	Posterior odds $\frac{P(BM_1 V_{BM_j}, K_0)}{P(BM_0 V_{BM_j}, K_0)}$	Posterior probability $P(BM_1   V_{BM_j}, K_0)$	Posterior probability $P(BM_0   V_{BM_j}, K_0)$	$\bar{u}(a_1)$ vs $\bar{u}(a_0)$	
0.01/0.99	0.0011/0.0226	0.0469	0.9531	1.422	7.812
0.02/0.98	0.0022/0.0223	0.0905	0.9095	1.814	7.638
0.025/0.975	0.0028/0.0222	0.1119	0.8881	2.007	7.552
0.03/0.97	0.0033/0.0221	0.1299	0.8701	2.169	7.480
0.05/0.95	0.0056/0.0217	0.2051	0.7949	2.846	7.180
0.10/0.90	0.0111/0.0205	0.3512	0.6488	4.161	6.595
0.20/0.80	0.0222/0.0182	0.5495	0.4505	5.946	5.802

Table 11.7: Changing the prior odds on  $BM_1$

than the alternative option. Table 11.3 shows how the posterior odds and the utilities of the decision-options change when the prior odds change:

The option of "positive relevance" becomes available when the prior odds on  $BM_1$  get larger than 0.20.

However, this cannot change the likelihood-ratio. The information provided by the expert-knowledge concerning the bitemark's most likely causal biting-mechanism and most likely time of occurrence stays unaffected by the other evidence. The time of occurrence of the bitemark, on its own, yielded a likelihood-rate of 19:1 in favor of  $BM_2$ : The crime investigator will be evidence-based when recommending it to be "very likely" that the bitemark was made simultaneously with the crime act. But the question whether it was the suspect's biting-mechanism or someone else's which made the bitemark is far more uncertain. If the investigator assumes that the bitemark was made at the same time as the legally relevant injury, then the likelihood that the bitemark was made by the suspect's biting-mechanism is 4.9:1. This rate assumes that bitemark-experts would agree to the assumptions made for this analysis. Unfortunately it is impossible to know this. The bitemark-experts on the Torgersen-case hesitated to speak about their reference-classes, reflecting a general hesitance among bitemark-experts to do so — something which may partly be explained by the current methodologi-

cal norms adhered to by the experts. This may also explain why the current state of consensus among bitemark-experts about concepts and characteristics is fragile and the current state of knowledge about the causal mechanisms involved in bitemark-production in human skin is weak.

## 11.5 Conclusion.

In this chapter I have demonstrated how a particular subgroup of bitemark-problems could be solved under certain assumptions about the distribution of the characteristics involved and about the accuracies of the particular expert(s) requested to assist on the case. These assumptions were partly justified by the choices made by the experts in the Torgersen-case, partly by information in the published literature on bitemark-analysis, and partly by my own beliefs about natural language adjectives signifying proportions. The aim has been to demonstrate that evidence-basis may be achieved for bitemark-problems despite the lack of information of a kind usually associated with "evidence-based" knowledge. The criterion of evidence-basis is a logical and not a statistical one, requiring the decision-maker to close the space of possibilities — i.e. actually and explicitly specifying the alternative possibility or possibilities to the one suspected — in order to get a grip on the risk of incorrect decisions and use this to justify the decision about the consequences concerning aims and values specified for the decision. The aim has *not* been to say anything about the expert-conclusion in the Torgersen-case: Their conclusion may have correct or wrong, but as long as they did not want to speak about their reference-bases we may not assess that question. This also makes it impossible to assess whether the crime investigative decisions about the bitemark-means in the Torgersen-case actually achieved or undermined the aims and values of that decision.

In the last chapter I will relate the methodology and the suggested model to the worries voiced by Tribe (1971). I will also suggest a bitemark-procedure to the investigator wanting to evidence-base future decisions about bitemark-means.

# Chapter 12

## Conclusion

The basic question in this dissertation has been what it can and should mean to have an evidence-based crime investigation. This question has been asked for ethical, societal/political, and economic reasons. The ethical reasons are the same as those underlying the legal presumption of innocence and the principle that it is better to let ten guilty go free than to convict one innocent: An individual is as innocent and free as any other individual until *evidence to the contrary is presented by the accuser, in a court of law*. The detecting and assessment whether or not signs of guilt are true signs of guilt, whether evidence is evidence at all, is a matter of truth alone and is made during the crime investigative phase, and the suspect remains innocent until true signs exist. This belief that guilt can only be ascribed given true signs of guilt and not merely signs of guilt is thus an ethical issue and is reflected in practice in the separation between the investigative and the prosecutorial office. The question of what separates good evidence from less good evidence is thus also an ethical issue as it affects who is ascribed guilt and who is presumed innocent. The societal/political reasons concerns institutional legitimacy in modern, or rather, post-modern society: The citizen of modern European jurisdictions have become highly educated and is drilled in democratic ideals of equality and individual rights — they expect public decisions to be backed in principled reasoning and will protest decisions that only appeals to tradition or authority. This dissertation has been an effort to suggest principles for reasoning tailored to the crime investigative problem-situation, principles believed to answer this more demanding public. The economic reasons are the decreasing public budget at the same time as technologies rapidly changes and becomes more advanced, the amount of information only grows, and the

kinds of crime change. Choices will have to be made and the prioritizing must also be principled.

In the public health sector the principle of "evidence-based medicine" is seen as a sound principle for balancing the ethical, societal/political, and economic concerns. It is increasingly being enforced for not only decisions about treatment but also diagnostic decisions. In this dissertation I have argued that there are no epistemological differences between the inference-situation of the clinical diagnostician and that of the crime investigator: In both situations, the decision-maker has to make a choice and decide which of a set of alternative causal mechanisms is the most likely for a particular, uniquely conditioned, case, and the consequences of wrong decisions are equally grave. I thus suggest that the same basic principle as that underlying evidence-based medicine can be an equally sound principle for balancing the ethical, societal/political, and economic concerns relevant to crime investigative decisions.

When formulated in the terms relevant for the crime investigative context, the basic principle is identified to be the following:

**Premise 1.**

A crime investigative decision that a means of evidence is positively relevant with respect to a suspected hypothesis formulated in the terms of the anticipated indictment is *evidence-based* if and only if (1) the expected utility of a given set of observations (made by any kind of witness — lay, expert, or crime-investigator) is greater under the suspected hypothesis than under the negation of that hypothesis and (2) the expected utility of the given set of observations under the negation of the suspected hypothesis is justified (explicitly) to be sufficiently small for the anticipated role of the means of evidence.

In this dissertation I have analyzed the current crime investigative principles of reasoning, or norms of inference, for a delimited subgroup of crime investigative decision-problems — namely decisions about bitemark-means, in which forensic bitemark-experts are needed to assist on the analyses of the conditions involved. For this purpose I studied (1) the expert-reasoning behind a series of crime investigative decisions made about a bitemark-means in a historical case and (2) the reasoning of bitemark-experts as this is expressed in studies of the mechanisms involved in bitemark-production. In

the historical case, the experts did not provide the kind of information required for the crime investigative decision to be evidence-based according to the standard specified above, and only a minor proportion of the published studies did so for their decision to be evidence-based.

I had to conclude that the principle of inference identified for the bitemark-experts's reasoning — which I labelled "abduction with incomplete or open induction" — more likely than not is descriptive of the crime investigative reasoning as well. This does *not* mean that crime investigative decisions about bitemark-means are always wrong. But it does mean that there are then no inter-subjective means available to assess whether they are more often correct than wrong. In practice, it means that we have no precise instrument by which to assess whether the aims and values intended by these decision are more often achieved than not — or, in yet other words: we have no instrument by which to assess whether these decisions more often than not contribute to convict the true guilty and acquit the true innocent and thus protects the values expressed by the presumption of innocence and the principle of letting ten guilty free before convicting one innocent.

And neither does it mean that "abduction with incomplete or open induction" is generally wrong: It is probably the inference strategy most natural to most people and is the one most efficient when time is limited, the consequences are not too serious, or when there are good reasons to under-communicate uncertainty. The latter is the case at the end of the trial-phase: The need to reach a legal decision to which both parties can agree and the public can and will abide by, is a good reason to under-communicate uncertainty — if, that is, the court can take for granted that the crime investigation has assessed this uncertainty and found it sufficiently small for the legal purpose. But "abduction with incomplete or open induction" is just not suited for decision-problems where the main aim is justified, accurate, and impartial knowledge and where the consequences of being wrong are serious. To under-communicate uncertainty in this situation would be to undermine ones own aim.

Why is it then that crime investigators, if I am correct in suggesting them similar to the bitemark-experts, choose the above inference strategy? A possible reason can be that this is the strategy surviving when under constant influence from jurists, prosecutors, and solicitors (whose attention is fixed on the trial-phase's need for consensus and balance) and when not having the training, time, or resources to tailor their own methodologies.

In this dissertation I thus see neither epistemological nor institutional

reasons why crime investigative decisions about the relevance of means of evidence should not be evidence-based according to the standard identified above. This is also why I in the last part of this dissertation suggest Bayesian theory and a Bayesian Networks-methodology as a strategy to evidence-base such decisions. I try to be constructive by suggesting a solution, in the terms of this methodology, to the bitemark-problem, and by demonstrating how the reasoning via this methodology and my suggested model would work if having a bitemark-problem under conditions constructed to be as close as possible to those of the Torgersen-case.

The Bayesian Networks-methodology is a formal approach, based on basic rules of logic and probability-calculus, and does thereby insist on a certain level of precision with respect to the objects it includes or excludes from its concepts and terms. Indeed, this will involve degrees of reduction and bias, as Tribe (1971:1361-1366) claims in the argument I denoted by (1e.) in section 4.3 (Chapter 4) of this dissertation. But this reduction is not necessarily only to objects measurable via known standards and is not even exclusive to formal approaches — for is not reduction involved whenever one tries to capture something via any kind of language? Is an ambiguous term always more inclusive? Of course not, it may just as well be exclusive — the ambiguity being just a social, rhetorical, or political means, to either avoid offending someone or committing to something. Precision is also a means for something and is, just like ambiguity, neither good nor bad in itself. It is its use in specific situations which may be good or bad. And indeed there are of course sworn formalists who will approach reality as if it was one big Sudoku. But for the majority of the users of a formal approach, it is just an instrument in the effort to standardise inference and decision-making in situations where the consequences of wrong decisions to specified ethical and societal/political values as well as monetary or other more material values are serious. This is certainly my aim when I suggest using the Bayesian Inference-methodology to solve the bitemark-problem. For this kind of problem situation, the ambiguity about the reference-classes used when assessing the likelihood of a suspected hypothesis can be argued to be self-destructive: over time causing the public to loose confidence in the legal system because one prefers not to specify the reference-class already used when having passed judgement on the probability of a hypothesis.

The two worries about (1) inappropriate reduction and bias by preferring easily quantifiable aspects and (2) inappropriate choice of reference-classes are the only two worries expressed by Tribe (1971) which is relevant when

considering using formal approaches during the investigative phase and for the subgroups of decisions studied in this dissertation. The other worries are more relevant for evidence-assessment by a lay-jury during the trial-phase. And these worries are not difficult, for me at least, to agree on.

Now there is one question left: Say now that a crime investigator sees some sense in my arguments concerning the need to evidence-base decisions about the relevance of means of evidence, has a bitemark-problem with conditions approximating those I specified in chapter 10 of this dissertation, but has no time to review the bitemark-literature and not being familiar with formal methodologies. What can he/she do? We can of course not just e-mail him/her the likelihood-ratio or the utility-function. We can do as has been done in the medical context for years: Suggest a decision-guideline or a "best-practice"-procedure in which the conditions involved in a bitemark-means are specified, and also specify the questions under each condition which must be informed on by what kind of information from which kind of sources. The following is a possible sketch of what could be the content of such a best-practice-guideline for bitemark-problems (this is a sketch and not an actual guideline).

## **Core conditions for positively relevant bitemark-means**

(one-offender cases)

1. The suspected bitemark must be in category 2, 3 or 4 on Pretty (2006)'s Bitemark Severity and Significance Index (see Figure 12.1 below);
  - The classification can be performed by investigator (Non-experts (police-officers) participating in the validation-study of the index showed high inter-examiner reliability.)
2. The suspected bitemark must be diagnosed to most likely have occurred within the same interval of time as that identified for a control-injury known to be related to the legally relevant injuries:
  - the expert must provide

- (a) the probability of observing two similar profiles if the suspected hypothesis were true ("the suspected bitemark and the control-injury was made during the same specified time interval);
- (b) the probability of observing two similar profiles if the negation of the suspected hypothesis were to be true ("the suspected bitemark and the control-injury was not made during the same specified time interval — i.e. but during an event irrelevant to the crime event);
- (c) the medical markers used for the profiling of the two skin-injuries must be specified in medical terms or terms agreed on among the forensic examiners;
- (d) the joint discriminatory potential of the markers must be informed on: Result from relevant population study is best but subjective/intersubjective estimate is good enough;
- (e) the control-injury must be explicitly justified to have the same initial conditions as the suspected bitemark;
- The probability under (a) must be greater than the probability under (b);
- justification for the reference-basis used for expert item (b) (co-operation necessary due to case-contingent size for time-interval);
- the person with the suspected bitemark must not have been abnormally prone to abuse.

3. The suspected bitemark must most likely be a human bitemark:

- the expert must provide
  - (a) the probability of observing the characteristics used for this diagnosis if the suspected hypothesis were true ("The suspected bitemark is a human bitemark");
  - (b) the probability of observing the characteristics used for this diagnosis if the negation of the suspected hypotheses were true ("The suspected bitemark is not a bitemark but something else — an animal bitemark, an object with teethlike forms, an internally caused irregularity");
  - (c) the characteristics used for this diagnosis must be specified in dermatological terms or terms agreed on among forensic examiners and bitemark-experts;

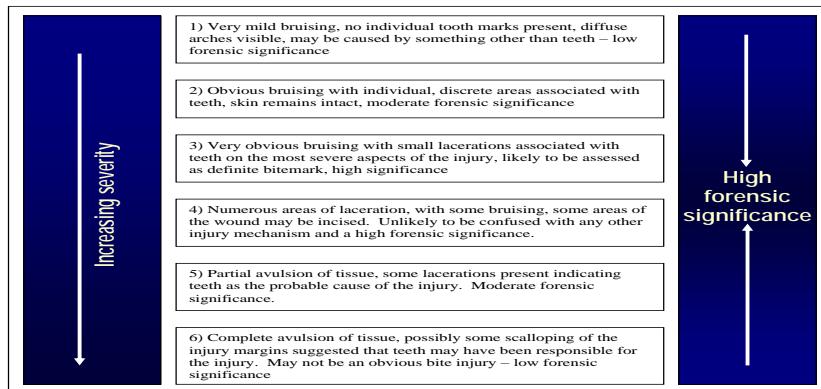
- (d) the joint discriminatory potential of the characteristics must be informed on: Result from relevant population study is best but subjective/intersubjective estimate is good enough;
  - (e) justification for the reference-basis used for item (b);
- The probability under (a) must be greater than the probability under (b);
- the person with the suspected bitemark must not have been abnormally prone to abuse.

4. The identified suspect's biting-mechanism must be the most likely cause of the bitemark:

- the expert must provide
  - (a) the probability of observing similar profiles if the suspected hypothesis were true ("The suspect's biting-mechanism is the cause of the bitemark");
  - (b) the probability of observing similar profiles if the negation of the suspected hypotheses were true ("The suspect's biting-mechanism is not the cause of the bitemark — i.e., someone else's biting-mechanism is the cause of the bitemark");
  - (c) specification of each of the characteristics constituting both the two profiles used for this diagnosis: The bitemark's profile must be specified in dermatological terms; the biting-mechanism's profile must be specified in odontological terms — or terms agreed on among forensic examiners and bitemark-experts;
  - (d) estimates of the degree of covariation within and between each pair of corresponding bitemark- and biting-mechanism characteristics: Results from relevant larger scale studies are best but subjective/intersubjective estimates are good enough;
  - (e) estimates of the discriminatory potential of each of the pairs of characteristics: Result from relevant population study is best, but subjective/intersubjective estimate is good enough;
  - (f) justification for the group of individuals selected for items (b) and (e);
- The probability under (a) must be greater than the probability under (b).

Any one of the numbered conditions failing is reason to decide "not positive relevance".

**FIGURE 1 – Range of bitemark severity – the Bitemark Severity & Significance scale**



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Figure 12.1: Bitemark Severity and Significance Index (Pretty 2006).

This guideline is of course just a sketch to indicate the outline of a possible future bitemark-guideline and is not intended for practical use. A useful guideline will have to be formulated and authorized in cooperation with crime investigators, bitemark-experts, and the legal agents being served the information thus gathered — to ensure a beneficial contribution of the guideline. Having suggested this preliminary bitemark-guideline to a crime investigator with a bitemark-problem I am at the end of this dissertation. I hope to have contributed in a constructive way, as was the intention, to the discourse on methodology, inference and inquiry in general and to these concepts as they are relevant to crime investigation within the legal institution.

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## Appendix 1

### A brief introduction to the Norwegian legal system

The Norwegian legal system (attention to criminal law and procedure only) belongs to the civil law-systems, with its attention to codified laws and theoretical texts more than case-based precedence; with an inquisitorial trial process rather than an adversarial; with a rather active (professional) judge with independent adjudicative powers, usually accompanied with non-expert or expert lay judges (randomly selected), and sometimes with a jury; and with its preference for the principle of free admittance of evidence with few codified norms governing the kind of evidence admitted in a criminal case. The courts are independent of the other branches of the Norwegian government and are administrated by The National Courts Administration, the members of which are appointed by the national Assembly and the King-in-Council. (Wacks 2008, Hov 1999)<sup>1</sup>

The ordinary courts consist of three instances: *The District Court* (66) decides criminal cases by guilty plea or by a mixed panel of professional and lay judges. Judgements here may be appealed to the next instance, the Court of Appeal. *The Court of Appeal* (6 circuits) hears appeals against decisions by the District Court, and in case of appeal against the issue of guilt a jury or a bench of three professional and four lay judges will review the case (the reasons of the decisions are not given). In cases of sentencing more than 16 years a jury (10 lay members) hears the case. In 1995 Norway introduced a two-instance system in which all cases can be tried in both first and second instance. Before 1995 serious criminal cases were brought directly before the Court of Appeal. *The Supreme Court* has 19 judges. Its Appeal Committee assesses a cases eligibility for the Supreme Court. In criminal cases the Supreme Court hears only appeals against sentencing and procedure (not guilt). Its decision and reasoning are written and public.<sup>2</sup>

Norway is signatory to various international conventions, including the European Convention of Human Rights and is subject to the European Court of Human Rights.<sup>3</sup>

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<sup>1</sup><http://www.domstol.no/default2916.aspx?epslanguage=EN> accessible by June 2010.

<sup>2</sup><http://www.domstol.no/default2916.aspx?epslanguage=EN> accessible by June 2010.

<sup>3</sup><http://www.regjeringen.no/en/dep/jd.html?id=463> accessible by June 2010.

The Norwegian Prosecuting Authority is organised on three levels — The Director of Public Prosecutions; The Public Prosecutors; and The Prosecuting Authority in the Police — and is responsible for the investigation of criminal cases and for the prosecution of a criminal case if it is decided —normally by the Prosecuting Authority attached to the police, in more serious case by Public Prosecution in the area of the case or by the Director of Public Prosecution — that the case should be brought to the court for trial. The public prosecutor in a given region is responsible for its police districts (A separate national prosecuting authority exists for the instruction and supervision of investigation of organised crime and serious crime. The investigation of such crime is performed by specialised investigative organisations)<sup>4</sup>

A crime investigation is initiated and led by the police's law-enforcement personnel who may, but need not have prosecutorial authority. An investigation will be in continual contact with the prosecutorial and general court-authorities as these have to authorise, and sometimes initiate, a variety of investigative steps. Any investigation is subject to laws, regulations, and directives. For example, with respect to investigative strategy *The Norwegian Criminal Procedure Act (1981/2006)*, Section 226, states that

The purpose of an investigation is to obtain the necessary information

- a) for deciding whether an indictment should be preferred
- b) to serve as preparation for the court's trial of the issue of guilt and any issue concerning the determination of a sanction, and
- c) to prevent or stop criminal acts
- d) in order to execute sentences and other sanctions, and
- e) to serve as a preparation for the child welfare service to deal with the issue of whether measures shall be instituted pursuant to Act 17. July 1992 No. 100 relating to child welfare services.

The provisions of chapter 13 apply to social inquiry and mental observation

If a specific person is under suspicion, the investigation shall seek to clarify both the evidence against him and the evidence in his favour.

The investigation shall be carried out as quickly as possible and in such a way that no one is unnecessarily exposed to suspicion or inconvenience.

**Forensic scientific resources:** The investigator in charge of a criminal investigation has access to permanent *forensic technicians*, who are police-college educated and specialised on fingerprints, crime scene photography,

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<sup>4</sup><http://www.riksadvokaten.no/ra/ra.php?infoid=12>

etc. or university or college educated chemists, engineers, etc., and *forensic medicine personnel*, who are university educated geneticists, pathologists, biologists, etc. According to need the investigator may request external expert-assistance — such as forensic dentists. The case-specific appointment, use, and performance of external scientific expertise are regulated by law (*The Norwegian Criminal Procedure Act 1981/2006*: Chapters 10 and 11).

The legal status of scientific experts may vary: A *court-appointed expert* is expected to work impartially, to assist the court and must produce a written report which by law needs to be accredited by The Board of Forensic Medicine (se below). An expert is obliged to assist if appointed by the court, is obliged to testify in court; must attest to being conscious of his or her responsibility, and has expenses covered by the court. Usually only one expert is appointed on given issues and both parties must agree to the choice. An *expert witness* is appointed and paid by one of the parties to serve his/her needs and need not produce written statements accredited by the Board of Forensic Medicine. This experts legal status is similar to that of an ordinary witness.

**Internal and external quality control of forensic technical and scientific resources** in Norway: By 2001 only the *Division of Forensic Toxicology and Drug Abuse* at Institute of Public Health Norwegian had been accredited to ISO-standard (see internet site below). The other institutes, laboratories, or individual expert disciplines employed for forensic investigation had no such accreditation/certification by any external body. No external formal criteria existed for their services and the institutes, laboratories, or subject disciplines had not formalised internal criteria. Yet there existed an assessment mechanism by the existence of The Norwegian Board of Forensic Medicine. This Board accredited the work of court appointed experts (medical or other) in given cases, was regularly consulted in particular issues or cases by the court, and stayed in close contact with and arranged courses and seminars for experts, investigators, lawyers and judges. This Board thus had a certain normative power balancing the lack of regular and standardised accreditation, an authority which was secured in section 146 in *The Norwegian Criminal Procedure Act (1981/2006)*. The Board is national and appointed by the Ministry of Justice. (NOU 2001:12; chapters 9-10) <sup>5</sup>

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<sup>5</sup><http://www.justisecretariatene.no/en-gb/Innhold/The-Commission-for-Forensic-Medicine/>

**The Norwegian Criminal Cases Review Commission** was established as an independent legal body in 2004. The Review Commission is not an ordinary legal body — it may not itself produce legally enforceable decisions in given cases, but, if reopening is decided, the commission will refer the case back for retrial at the same court-level it was last decided. Only if new circumstances, new evidence, or other conditions (as defined in Sections 390-393 of the Norwegian Criminal Procedure Act) have come into existence since the last court decision can the Commission decide to reopen the case by sending it back to court for retrial. (*The Norwegian Criminal Procedure Act 1981/2006*, <http://www.gjenopptakelse.no/index.php?id=30>, accessible by June 2010))

The Review Commission assessed Torgersen and his counsellors motion for review with respect to the following two sections of the Norwegian Criminal Procedure Act:

### **Section 391**

In favour [note 1: See Section 390, first part, relate to section 393.] of the person charged reopening of a case may be required:

- 1) when [note 2: See Section 393 first part, nr.1.] a judge, member of the jury, keeper of the records, police officer, or official in the prosecuting authority, prosecutor, defence counsel, expert or court interpreter has been guilty of a criminal offence in relation to the case, or a witness has given false evidence in the case, or a document that has been used in the case is false or forged, and it cannot be excluded that this affected the judgement to the detriment of the person charged,[note 3: Compare to *Dispute Act* Section 407 nr.1 to nr.3.]
- 2) when an international court or UN human rights committee has in a case against Norway found that[note 4: Compare to *Dispute Act* Section 407 nr.7.]
  - a) the decision conflicts with a rule of international law that is binding on Norway, and it must be assumed that a new hearing should lead to a different decision, or
  - b) the procedure on which the decision is based conflicts with a rule of international law that is binding on Norway if there is reason to assume that the procedural error may have influence the substance of the decision, and that a reopening of the case is necessary in order to remedy the harm that the error has caused,
- 3) when a new circumstance is revealed or new evidence is produced which seems likely to lead to an acquittal or summary dismissal of

the case or to the application of a more lenient penal provision or a substantially more lenient sanction. In a case in which a custodial sentence, committal to compulsory mental health care pursuant to section 39 of the Penal Code, compulsory care pursuant to section 39 a of the Penal Code or loss of civil rights[note 5: Relate to *Penal Code Section 29.* ] is not imposed, new information or evidence that the person concerned should have presented at an earlier stage may not be produced. [note 5: Relate to Sections 390 and 392. ]

### **Section 392.**

Even though the conditions prescribed in 390 or 391 are not fulfilled, the court may order the case to be reopened in favour of the person charged when the Supreme Court has departed from a legal interpretation that it has obviously adopted and on which the judgement is based.

The same applies when special circumstances make it doubtful whether the judgement is correct, and weighty considerations indicate that the question of guilt of the person charged should be tried anew. (*The Norwegian Criminal Procedure Act 1981/2006*)

**The following links may provide more information:**

**The Norwegian Ministry of Justice and the Police:** [www.regjeringen.no](http://www.regjeringen.no);

**Lovdata:** [www.lovdata.no](http://www.lovdata.no); an institution initiated by the Norwegian Ministry of Justice and the Law Faculty at University of Oslo for the purpose of establishing and managing systems of legal information. Its internet site contains the primary legal sources regulating the Norwegian citizens' rights and obligations. The information is free of charge and contains statutes, central and local administrative regulations, and the more recent decision by the Supreme Court and the Court of Appeal;

**The National Courts Administration:** [www.domstol.no](http://www.domstol.no)

**The Norwegian Higher Prosecuting Authority:** [www.riksadvokaten.no](http://www.riksadvokaten.no);

**The Norwegian Police:** [www.politi.no](http://www.politi.no)

**Norwegian Criminal Case Review Commission:** [www.gjenopptakelse.no](http://www.gjenopptakelse.no)

**The Norwegian Board of Forensic Medicine:** [www.justissekretariatene.no](http://www.justissekretariatene.no)

**The Institute of Forensic Medicine:** [www.med.uio.no/rmi/](http://www.med.uio.no/rmi/); this institute is a unit of the medical faculty of University of Oslo. In addition to regular university functions the institute serves the police and the Courts, mainly on forensic genetics and forensic pathology.

**The Norwegian Institute of Public Health:** [www.fhi.no](http://www.fhi.no); the Institute's **Division of Forensic Toxicology and Drug Abuse** is the main unit assisting the police and the courts concerning the analysis and interpretation of biological samples' with respect to alcohol, drugs (medicinal and illegal) and toxic agents in legal cases.

## Appendix 2

### Forensic odontologist F. Stroems written report on the bitemark in the Torgersen-case

(The report is translated by the author of this dissertation)

Dentist Ferdinand Strm  
Regular Forensic Dentist  
Teacher in forensic dentistry,  
School of Odontology, Oslo  
28.April 1958

To Oslo Court of Preliminary Hearings

Report

Bitemark examination of the murdered Rigmor Johnsen [date of birth].<sup>6</sup>.

At 09.00am, 7-12.1957, I was called on the phone by Professor G Waler [the forensic medical examiner on duty] who informed that a 16 years old girl was found killed and that the body had been transported to the Institute of Forensic Medicine (IFM). A bitemark appeared visible on one of the victims breasts, and he asked for my assistant examination of the body. I arrived at IMF 09.30am. The medical examination had not yet been initiated, and the body was in the position shown on figure 1. [Figure 1. missing from Excerpts].

I could immediately conclude the explicit presence of marks from biting in the left breast, 3 of the marks were from the upper jaw and 3 to 4 from the lower jaw. It must be assumed that it was the front and right side teeth that had been operant in the biting.

[...]

The breast was photographed in natural scale. Figure 2 [figure 2. is missing from excerpts]. The bitemarks were numbered 1 to 7, as I started from the upper left and went right and round. See Figure

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<sup>6</sup>The photographic documentation cited in Stroem 1958, is, as it is represented in the Excerpts, either missing or is of such poor quality that it is omitted. Only the photograph of the anomaly on RJs left breast taken by either Stroem or the medical examiner at the time of examination and Ts set of teeth at the time of examination is included

3. [Figure 3. is present in *Excerpts*, but poorly represented a hand drawing]

The picture in Figure 4. is by an enlarged scale [Figure 4 is missing from *Excerpts*].

**Bitemark nr.1** Biting through the skin, upper jaw

**Bitemark nr.2** Biting through the skin, upper jaw

**Bitemark nr.3** Biting through the skin, upper jaw

**Bitemark nr.4** Biting through the skin, lower jaw

**Bitemark nr.5** Biting through the skin lower jaw

**Bitemark nr.6** Impression, no blood assembled under the mark, lower jaw

**Bitemark nr.7** Possible impression, no blood assembled under the mark, lower

Bleeding from the bite-wounds could not be seen, not blood-assembling under the marks either.

A plaster-imprint was taken of the breast. Figures 5 and 6 show photographs of this imprint, of bitemarks from the upper jaw and the lower jaw respectively. Figure 7 shows a picture of the two pictures mounted so as to represent the position of the bitemarks as they appear on the plaster impression. The three pictures are enlarged 2,5 times.

During my analysis the 7-12-57 I expressed to Police Constable Haukenaes that the one who performed this biting must have severely worn teeth in the lower jaw. After having made the plaster impression, the breast was cut off from the body and put in preserving liquid.

The same day, 7-12-57, at 14.30pm, I went with PC Haukenaes to [the police station where F.F. Torgersen [FT] was kept] in order to take an impression of the teeth of [FT]. I talked to the suspect and noticed that his right front tooth had had a corner broken off. I asked when this had happened. He answered that it happened several years ago. The suspect did not want to provide an imprint without a lawyer present.

I tried again Wednesday 12-12-1957, but he still would not provide an imprint.

Being requested by the Oslo Court of Preliminary Hearing and by the Oslo Police, I went to Bodsfengslet [prison in Oslo] to examine Jon

Roger Langbraatens [L] teeth. He bit into plastelin and an imprint of his teeth was made. Report was sent to Oslo Police 26. March 1958. Figure 8 and 9 [both present in *Excerpts*, but omitted] shows models of his teeth made, respectively, from the plastelin-imprint and the imprint made of his full set of teeth. Figure 10 [both present in *Excerpts*, but omitted] shows a photography of the plastelin-imprint

My conclusion from this examination is:

After a very thorough analysis of this material compared to with the material of the bitemarks in the murdered RJs left breast, I find the deviations to be so extensive that I with certainty can exclude [L] as the one who performed this bite.

12-4-58 I was requested by Judge Koren to, together with him and [FT]s lawyer, to meet with the accused. The accused was now willing to provide an imprint on the condition that if I was not able to exclude him a second dental expert should be appointed. This was agreed. 14-4-58 I made an imprint of his teeth and let him bite into plastelin. He was helpful, and I got the best imprints. Models were made from both the imprint of the whole set of teeth, figure 11, and from the imprints in plastelin, fig 12 [present in *Excerpts*, but omitted]. Fig.13 and 14 [both present in *Excerpts*, but omitted] shows a photo of the imprint in plastelin, from the upper jaw and the lower jaw respectively.

From the models Fig.11 [present in *Excerpts*, but omitted] it is visible that the suspect has a so-called edge to edge bite, i.e. that the front teeth, when occluded, meet at the cutting edges. This is a deviation from the ordinary norm of upper jaw front teeth more or less covering the lower jaw front teeth.

Due to this peculiar positioning of the teeth the, cutting edges of the teeth have characteristic furrows, both in the upper jaws middle front teeth and in the lower jaws middle front teeth, especially explicit in the front middle teeth. The corner of upper jaws right mid front tooth - the corner closest to the side front tooth is broken off, and the corners of the lower jaws middle front teeth is, due to wear and splintering, less characteristic.

The suspect has good regularly positioned teeth, but due to the peculiar positioning of the set of teeth, the edge to edge bite, he has, as mentioned, acquired characteristic furrows in the front teeth, in addition to the upper jaws middle front tooth having a defect corner that is visible from the outside. The same is the case for the lower jaws middle front tooth where the corner nearest to the midline is defect, also visible from the outside, and a space in the midline in the cutting

edge is thus occurring. A set of teeth such as that of the suspect with an assembly of characteristics should thus be particularly suitable for identification.

On the murdered we found, as mentioned, several marks, we see thus explicit marks from two upper jaw middle front teeth and impressions of two lower jaw front teeth. The bite performed is not done in order to bite off a piece, but is a so called pleasure bite, combined with sucking on the nipple of the breast. Due to the ball-shaped form and the plasticity of the skin of the breast a bitemark here will appear differently than that made into an apple. We do not know the position of the part of the breast that was bitten relative to the teeth-rows during the biting.

Another thing is that it does not make much sense to measure the lengths of the bite marks in human skin, as the elastic fibres of the skin will contract the marks when biting stops and as the vaulted form of the breast makes it difficult to produce a measurement that is comparable to the suspects teeth.

In these bites it will therefore be studied whether the characteristics found in the teeth of the suspect can be found in the bitemarks of the breast.

Suspect [FT]s teeth has, as mentioned, a series of characteristics in the cutting edges of both the upper and lower jaws middle front teeth. These characteristics are to be found also in the bitemarks.

**Bitemark nr.1** represents the furrow in the cutting edge of upper jaws left middle front tooth.

**Bitemark nr.2** represents 2/3rd of the cutting edge of upper jaws right middle front tooth (the part towards the midline), and shows clearly the jagged front cutting edge. The part away from the midline is not bitten into the skin because it is broken off.

**Bitemark nr.3** must be from the right side front tooth, but has, as the tooth itself, no characteristics and is only partly recognised.

**Bitemark nr.4** must be from the lower jaws right canine tooth but is without characteristics, as is the tooth itself.

**Bitemark nr.5** is from right middle front tooth and is re-presented with all characteristics. Especially explicit is the cob [/flask/spadix] shaped extension in the furrow.

**Bitemark nr.6** is from the left middle front tooth and re-presents all the tooths characteristics, especially prominent is the straight furrow.

**The space** between the two middle front teeths cutting edges in the lower jaw of [FT] (earlier mentioned), is clearly present in the bitemark.

Stereoscopic images for comparing the bitemarks and the cutting edges of [FT]s teeth are made, Fig.15,16,17, and 18 [all present in *Excerpts*, but omitted].

Conclusion. An odontological examination of a bitemark-trace compared with the suspects teeth will, if there do not exist accordance [/agreement/similarity], imply absolute acquittal for the suspect. Differently if existence of accordance [/agreement/similarity]. In this case there will always be judgements and there should be exhibited care, if there are no details that are judged to be particularly characteristic.

The teeth of suspect [FT] have a series of particular characteristics that without exception is to be found re-presented in the bite-traces of the murdered. From a scientific point of view it is my opinion that it is predominantly probable that the bitemark in RJs breast is from the suspect [FT].

Based on my personal experience, well informed about my responsibility, I assess the bitemark in the breast of the murdered to be identical [Stroms underlining] to the teeth of the suspect [FT].

[Stroms signature] Ferdinand Strom

P.S. I have also taken imprint in plastelin of Svein Erik Johansen [J]s teeth Fig.19 which was without the characteristics expressed by the bitemark.

## Appendix 3

### Published literature on bitemark analysis 1976-2008.

This appendix contains the collection of papers and books on forensic bitemark analysis published through international scientific journals. The main and basic procedure for retrieving the items was by using Metalib of the Library Services of the University College of London (UCL): All the possible spelling combinations of *bitemark* and *teethmark*, including singular/plural (bite(s), bitemark(s), bite mark(s), bite-mark(s), etc.). was used. The only condition specified was that of year of publication (from 1970 through 2008). The search was *not* conditioned by discipline as bitemark-analysis by nature extends into several disciplines. The resulting collection was then subjected to a hand search for items somehow slipping through the main search. A third procedure consisted in consulting the literature identified by the main organisations representing regional or international forensic odontologists. The final collection of items was made by removing any item not belonging to the following class of objects: *Forensic analysis and diagnosis of bitemarks by human teeth on human skin*. Membership was of course not always clear cut: Some items mention bitemarks only as relevant for a non-bitemark question; some were felt should have been considered too a-analytical for publication in a scientific journal — by being descriptive in a more or less ad-hoc fashion or by being singularly praising or denouncing bitemark-analysis or some aspect of it.

This final class of papers or books is considered to be an as complete as possible class with respect to being relevant for the questions asked in this dissertation.

The concepts used for classification of the papers:

**Evidence-based:** A study (1) of a specified delimited empirically testable hypothesis; by (2) ordered observable information (not necessary numerical) on specified characteristics; through (3a) an identified, specified, ethically justified/justifiable and understandable<sup>7</sup> technical procedure (enabling independent repetition of experiment) (3b) an identified or identifiable inference methodology which enable(d) an

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<sup>7</sup>Understandable to those having the same kind or level of training as the author of the experiment — who might want to repeat the experiment.

assessment of the likelihoods (not necessary numerical) of the hypothesis possibilities; and (4) including an assessment of the bias, or its effects on representational ability, involved by the specification of the hypothesis, the sampling procedure, or the technical procedure of the experiment;

**Descriptive/normative** A study which either (a) aims to be creative, constructive, informative, introductory or critical and have no intention to systematically justify or test the truth/likelihood of a delimited hypothesis, or (b) aims or claims to have tested hypothesis but fails satisfying the above definition of "experiment";

**Case-study:** A study describing the characteristics and conditions of a particular bitemark-case or a particular instrument/material/technique used in bitemark-analysis;

**Historical or Review:** A study describing the development of a phenomenon over time; and

**Legal case:** A description of a bitemark-case legally processed in some jurisdiction.

392 studies were retrieved through the searching procedure.

## 1976

MacDonald, D.G., Laird, W.R., (1976) Bitemarks in Murder case *Int J Forensic Dent*: 3(10) 26-30  
(Case-study; population-comments)

Vale G. L. Sognnaes R. F., Felando G. N., Noguchi T, (1976) Unusual three dimensional bite mark evidence in a homicide case. *J. Forensic Sci.* Vol. 21:642-652  
(Case-study)

Sognnaes, R. F. (1976) Dental science as evidence in court *Int J Forensic Dent* 1976; 3(9):14-6  
(Case-study, court-presentation)

Anderson W. R., Hudson R. P., (1976) Self inflicted bite marks in battered child syndrome *Forensic Sci.* 1976; Vol. 7: 71 - 74  
(Case-study; victim's biting-mechanism into biter population)

Bang G., (1976) Analysis of tooth marks in a homicide case. Observations by means of description, stereophotography, SEM and stereometric graphic plotting *Acta Odontol. Scand.* 1976; 34: 1-11  
(Case-study, instrument (Scanning electron microscopy))

Rawson, (1976) Solarisation as an aid to bite-mark analysis. *Int. J. Forensic Dent.* Vol. 3. Page 31  
(Descriptive, Instrument (Solarisation), BMA-general)

Goodbody, R.A. (1976) Turner, C.H., Turner, J.L. The Differentiation of Toothed Marks: Report of a Case of Special Interest *Med Sci Law* 1976; 16(1): 44-8  
(Case-study, Initial differential diagnosis)

Farr, ? (1976) Bite Mark Crucial in Murder Verdict *L.A. Times*, 1976, Nov. 4, pt. 2, at 3, col. 1.  
(Newspaper, comment on case, People v. Slone trial in California)

*People v. Milone* 43 Ill. App. 3d 385, 356 N.E.2d 1350 (1976)  
(Legal case)

## 1977

Luntz, L. (1977) History of Forensic Dentistry *Dental Clinics of North America* 1977; 21:7-17  
(History of BMA)

Christensen, M.S., Hargen, C.W., Nact, S., Gans, E.H. (1977) Viscoelastic Properties of Intact Human Skin: Instrumentation, Hydration Effects, and the Contribution of the Stratum Corneum *J. Invest Dermatol* 1977; 69: 282-286  
(Descriptive, skin-properties general, not bma-related)

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(Descriptive, reliability of bma)

Vale, G.L. (1986) Bite mark evidence in the investigation of crime *CDA J* (California Dental Association Journal) 1986:14(3):36-42  
(Descriptive, general bma)

Wagner, G.N. (1986) Bitemark identification in child abuse cases *Pediatr Dent* 1986: 8 (May, 1 Special): 96-100  
(Descriptive, introduction/manual for bma)

*Wade v. State* 490 N.E. 2d 1097 Ind. (1986)

(Legal case)

*State v. Stinson*, 134 Wis. 2d 224 at 228, n.2, 397 N.W. 2d 136 (1986)

(Legal case)

*People v. Marsh*, 409 Mich. 110 at 111; 293 N.W. 2d 588 (year unknown)

(Legal case)

## 1987

Warnick AJ, Biedrzycki L, Russanow G., (1987) Not all bite marks are associated with abuse, sexual activities, or homicides: a case study of a self-inflicted bitemark *J Forensic Sci* 1987;32(3):788-92  
(Case-study, victim into the biter-population)

Dorion, R.B.J. (1987) Transillumination in bite mark evidence *J Forens sci* 1987;32(3):690-7

(Descriptive, instrument (transillumination) for observing characteristics of bitemarks on human skin)

Dorion, R.B.J. (1987) Experimental Three-Dimensional Ruler for Use in Bite Mark Evidence *AAFS Meeting Odontology Section* San Diego February 16-21 1987  
(Descriptive, instrument (scale))

Farrel W. L., Rawson R. D., Steffens R. S., Stephens D., (1987) Computerised axial tomography as an aid in bite mark analysis: a case report *J. Forensic Sci.* 1987; 32: 266-272  
(Descriptive, instrument (Computerised Axial Tomography), case-study, for observing characteristic (biting-edge) of biting-mechanism).

Barsley R. E., Lancaster D. M., (1987) Measurement of arch widths in a human population. Relation of anticipated bitemarks. *J. Forensic Sci.* 1987;32: 975-982  
(Experiment, characteristic (arch-width) of biting-mechanism in given population)

Dailey, J.C. (1987) Identification Strength scale (Short letter to editor) *Journal of Forensic Sciences* 1987;32(2,March):?  
(Descriptive, instrument (certainty scale) for diagnoses of individual causal mechanism, not bma-related)

West M. H., Billings J. D., Frair M. S., (1987) Ultraviolet photography: bitemarks on human skin and suggested technique for exposure and development of reflective ultraviolet photography *J. Forensic Sci.* 1987;32: 1204 -1213  
(Descriptive, instrument (UV-photo), for observing characteristics for diagnosing age of bitemark on human skin (kind=fair skin))

West, M., Friar, J. (1987) The Use of a Video-Tape to Demonstrate the Dynamics of Bite Marks *J. Forensic Sciences* 1987; 34: 85-95  
(Descriptive, instrument (video) for learning about causal mechanism of BM)

## 1988

Vale GL, Rawson RD., [Comments on Rawson, R. D. et al (1986)'s reliability study of ABFO-GL84 scoring system] (1988) *J Forensic Sci* 1988: 33(1):20  
(Descriptive, instrument (ABFO-GL84 scoring system), comment on their 1986-study of reliability)

Hyzer WG, Krauss TC., (1988) The Bite Mark Standard Reference Scale—ABFO No. 2. *J Forensic Sci*; 33(2):498-506  
(Descriptive, instrument (The Bite Mark Standard Reference Scale—ABFO No. 2); Commented on by Ebert (1988))

Ebert J. L., (1988) Discussion of "The bite mark standard reference scale ABFO No. 2" (letter) *J. Forensic Sci.* 1988:(33):301-302  
(Description, instrument (ABFO-scale nr.2, photo), reliability; comment on Hyzer and Krauss (1988))

Lewin D. A., (1988) *The investigation of errors produced when photographing curved surfaces with relevance to bite marks and their photography*. Dissertation for Dip F. Od. London Hospital Medical Coll. 1988  
(Experiment, instrument (photo) for preserving/representing characteristics of bitemarks on curved objects, reliability)

Williams, A.R. (1988) Reflected Ultraviolet Photography in Dermatological Research *Journal Of Biological Photo* 1988: 56 (1) (January): 3-11  
(Descriptive, instrument (Reflected UV-photo), dermatology general, not bma-related)

Gordon, G.E., Johnson, G.H., Drennon, D.G. (1988) The Effect of Tray Selection on the Accuracy of elastomeric Impression Materials *66th Annual Meeting of the International Association for Dental Research* Montreal, Canada, March 1988  
(Description, instrument (impression materials), reliability)

Laiho, K. (1988) Peroxidase activity in traumatic Skin Lesions *Z. Rechtsmed.* 1988; 100: 65-72  
(Experiment, characteristic (Peroxidase activity) of skinmark for diagnosing age of skinmark)

Feather, J.W. (1988) A Portable Spectrometer for the Rapid Quantification of Cutaneous Haemoglobin and Melanin *Phys Med Biol* 1988; 33(6): 711-722  
(Descriptive, instrument (Portable Spectrometer) for observing characteristics (cutaneous haemoglobin and melanin) in skinmarks)

Benson B. W., Cottone J. A., Sperber N. D., (1988) Bite mark impressions: A review of techniques and materials *J. Forensic Sci.* 1988;33:1238-1243  
(Review of instruments for preserving/representing characteristics of bitemarks in different objects, reliability)

Vale, G.L. (1989) [Comment to Benson B. W., Cottone J. A., Sperber N. D. that his way is too cumbersome] *Journal of Forensic Sci* 1989;34: 4: 805-806, In Letters to the

Editor

(Descriptive, comment on Benson et al. (1988))

Benson B. W (1989) [Author responds to Vale (1989)] *Journal of Forensic Sciences* July 1989 Vol 34, Iss. 4, 805-806, In Letters to the Editor (Descriptive, answer to Vale (1989)'s comment on Benson et al. (1988))

Sperber, N. (1990) [Agrees with coauthor Benson (1989) above] *Journal of Forensic Sciences* July 1990;35(4): 777, In Letters to the Editor (Descriptive, comment on Vale (1989) and Benson et al. (1988, 1989))

Vale, G.L. (1990) [and Vale responds again] *Journal of Forensic Sciences*, July 1990;35(4): 777, In Letters to the Editor (Descriptive, comment on Sperber (1989), Vale (1989), and Benson et al. (1988, 1989))

Sperber, N.D. (1988) Styrofoam - A Valuable Tool in Bite Mark Investigations *Abstracts F-18, 40th Annual Meeting American Academy of Forensic Sciences, the Odontology Section, Philadelphia, P.A.* 18 February 1988 (Descriptive, instrument (styrofoam) for preserving/representing characteristics of biting-mechanisms, reliability)

Wetli, C.V., Mittleman, R.E., Rao, V.J. (1988) *Practical Forensic Pathology* Igaku-Shoin, New York 1988 (Descriptive (Book), Introductory/manual to forensic pathology)

Katz, J.O., Cottone, J.A. (1988) The present direction of research in forensic odontology *J Forensic Sci* 1988; 33 (6) (November): 1319-1327 (Review, forensic odontology general)

Barry, R.J. (1988) Forensic Odontology: Identification Through Dental Evidence NCJ 112875 *Police Chief* 1988;55(8):69, 72-78 (Descriptive, introductory/manual forensic odontology and bma)

## 1989

Gundelach A., (1989) Lawyers' reasoning and scientific proof: a cautionary tale in forensic odontology. *J Forensic Odont* ;7(2):11-6 (Descriptive, case-study, legal needs and bma-reliability (caution))

Whittaker D. K. (1989) The dentist's role in non-accidental injury cases, in Mason, J.K. (ed) (1989) *Paediatric Forensic Medicine and Pathology* 1989 London: Chapman & Hall (Descriptive, introduction/manual bma)

Bastien, R.B. Cheevers, L.S. (1989) Bite Mark Evidence in Criminal Investigations *R.C.M.P. Gazette* 1989; 51 (6,June): 18-21 (Descriptive, introductory/manual BMA general)

Gold, M.H., Roenigk, H.H., Smith, E.S., Pierce, L.J. (1989) Human Bite Marks: Differential Diagnosis *Clin Pediatr* 1989; 28(7): 329-331  
 (Descriptive, characteristics (various) of bitemarks in skin for diagnosing class and individual biting-mechanism)

Johnson, L. T., Cadle, D. (1989) Bite mark evidence. Recognition, preservation, analysis and courtroom presentation. *NY State Dent. J.* 1989; 55: 38-41  
 (Descriptive, introductory/manual bma-general)

Sperber, N. D. (1989) Bite marks, oral and facial injuries - harbingers of severe child abuse? *Pediatrician* Vol. 16. Page 207 to 211  
 (Descriptive, introductory/manual, bma-general)

West, M. H., Friar, J. (1989) The use of videotape to demonstrate the dynamics of bite marks. *J. Forensic Sci.* 1989; 34: 88-95  
 (Descriptive, instrument (video-tape) to understand causal mechanism of BM, reliability/distortion issues (yes says paper))

Tesdahl, D. B. (1989) Bite Mark Evidence: Making an impression in court *The Army Lawyer* 1989:13-26  
 (Descriptive, legal needs, reliability of bma)

Grey T. C. (1989) Defibrillator injury suggesting bite mark *Am J Forensic Med Pathol* 1989; 10(2) (June): 144-145  
 (Case-study, false bitemark-positive (true cause was defibrillator-pad))

Dailey, J. C., Shernoff, A.F., Gelles, J.H. (1989) An improved technique for bite mark impressions *J Prosthet Dent* 1989; 61(2, February):153-5.  
 (Descriptive, instrument (Polyether/polysulfide, polyvinylsiloxane material plus Easy tray-material) for preserving/representing characteristics of biting-mechanism)

Bishara, S.E., Jakobsen, J.R., Treder, J.E., Stasi, M.J. (1989) Changes in the Maxillary and Mandibular Tooth Size - Arch Length relationship from Early Adolescence to early Adulthood. A Longitudinal Study *Am J. Orthod* 1989; 95: 46-59  
 (Experiment, longitudinal study of characteristics (tooth size-arch length relationship), change from early adolescence to adulthood, not related to bma)

West, M. H., Friar, J.A., Seal, M. D. (1989) Ultraviolet Photography of Wounds on Human Skin NCJ 116061 *Journal of Forensic Identification* 1989:39:2(March-April):87-96  
 (Descriptive, instrument (UV-photo), for observing characteristics of skinmarks).

## 1990

ABFO *Bite Mark Analysis Guidelines* 1990  
 (Normative, (ABFO-guidelines), bma)

ASFO (1990) Qualifications and Requirements: Certification in Forensic Odontology  
*ASFO Newsletter* 1990; (Spring):2-3  
 (Normative, ASFO-criteria for certification of forensic odontologists)

Whittaker, D. K. (1990) Principles of forensic dentistry: 1. Identification procedures.  
*Dental Update* 1990:17(8)(Oct):315-21  
 (Descriptive, introduction/manual, forensic odontology general)

Whittaker, D. K. (1990) Principles of forensic dentistry: 2. Nonaccidental injury, bite marks and archaeology *Dental Update* 1990:17; 386 to 390  
 (Descriptive, introduction/manual, bma)

Kieser, J.A. Groeneweld, H.T., McKee, J., Cameron, N. (1990) Measurement Error in Human Dental Mensuration *Ann Hum Biol* 1990; 17:523-528  
 (Normative, reliability of instrument (measurement-techniques), for odontological purposes (potentially relevant for BMA-purposes))

Cua, A.B., Wilhelm, K.P., Maibach, H.I. (1990) Elastic Properties of Human Skin: Relation to Age, Sex, and Anatomical Region *Arch Dermatology* 1990; 282: 283-288  
 (Experiment, characteristics (elasticity) of human skin, by age, sex, and bodypart, not related to bma)

Sperber, N. D. (1990) Lingual markings of anterior teeth as seen in human bitemarks *J. Forens. Sci* 1990; 35: 838-844  
 (Experiment, characteristic (relative degree of disruption of skin) of bitemark on human skin, for diagnosing upper or lower dental arch; Commented on by West and Barsley (1991) comments on hypothesis and disagrees)

Allison, R. T. Whittaker, D. K., (1990) Use of benzidine for histological demonstration of haemoglobin in human bite marks *J. of Clinical Path.* 1990:43:600-603  
 (Experiment, instrument (histological technique, benzidine) for observing characteristic (presence of haemoglobin) of skinmark for diagnosing external or internal cause)

Barsley, R. E., West, M. H., Fair, J. A. (1990) Forensic photography. Ultraviolet imaging of wounds on skin *Am. J. of For. Med & Path.* 1990: 11: 300-308  
 (Descriptive, instrument (UV-photo) for observing characteristics (various) of skinmarks for diagnosing external or internal cause, teeth or other, human or animal)

Averill, D.C. (1990) *Manual of Forensic Odontology* American Society of Forensic Science, 1990 Colorado Springs  
 (Descriptive, introduction/manual, forensic odontology general)

Pierce, L. J., Strickland, D. J., Smith, E. S. (1990) The case of Ohio v Robinson. An 1870 bite mark case *Am. J. of Foren. Med & Path* 1990:11:171-177  
 (Legal case, first court case in USA?)

West, M. H., Barsley, R. E., Friar, J., Seal, M. D. (1990) The use of human skin in the fabrication of a bite mark template: two case reports *J. Forens. Sci.* 1990;35(6):1477-1485  
 (Descriptive, instrument/material (human skin, styrofoam) for preserving/representing characteristics of biting-mechanisms)

West, M. H., Barsley, R. E., Friar, J., Hall, F. (1990) Reflective Ultraviolet Imaging Systems (RUVIS) and the Detection and Documentation of Wounds on Human Skin *Journal Of Forensic Identification* 1990;40(5)(September/October): 249-255  
(Descriptive, instrument (RUVIS (UV-imaging systems)) for observing characteristics (?) of skinmarks for diagnosing presence or not of skinmark)

David, T.J. (1990) Documentation of a Seven Month Old Bite Mark with Ultraviolet Photography *The Annual Meeting of the American Academy of Forensic Sciences, Cincinnati*, February 1990  
(Case-study, instrument (UV-photo) for observing characteristics (?) of seven months old skinmark)

West, M. H., Barsley, R. E. (1990) First bite mark convictions in Mississippi *Mississippi D Ass J* 1990:46(4):7, 11-2  
(Review of legal bma-cases)

Clarke, E. G. (1990) The identification of maternity in an unusual pregnancy-related homicide *J. Forensic Science* January 1990, Vol. 35(1):80-88  
(Descriptive, case-study)

Sperry, K., Homer, R. C. Jr. (1990) An elliptical Incised Wound of the Breast Misinterpreted as a Bite Injury *Journal of Forensic Scientific Sciences* 1990; 35 (5) (Sept.):1226-1235  
(Case-study, false positive bitemark)

Syrjanen, S. M. (1990) Forensic dentistry - recent development towards an independent discipline in modern dentistry *Proc Finn. Dent. Soc.* 1990; 86(3-4):157-70.  
(Descriptive, introduction/manual, forensic odontology Finland)

*People v. Golub* 1990?  
(Legal case — cannot identify further)

## 1991

West and Barsley (1991) Discussion of Sperber (1990) [Lingual markings of anterior teeth as seen in human bite marks] *J. Forens. Sci.* 1991: 36: 303-307  
(Descriptive, comment on Sperber 1990):

Stechey, F. (1991) Bite marks and CANS - child abuse and neglect syndrome *Ontario Dentist* 1991:68:19-20  
(Descriptive, introduction/manual bma-general)

Sweet, D. J., Bastien, R. B. (1991) Use of an acrylonitrile-butadiene-styrene (ABS) plastic ring as a matrix in the recovery of the bite mark evidence *J. Forens Sci.* 1991; 36: 1565-1571  
(Descriptive, instrument (acrylonitrile-butadiene-styrene (ABS) plastic ring matrix) for preserving/representing characteristics of bitemarks on human skin)

Dailey, J. C. (1991) A Practical Technique for the Fabrication of Transparent Bite Mark Overlays *J For Sci* , 1991; 36:565-570

(Description, instrument (standard photocopying machine) for proding instrument (transparent overlay) for observing characteristics (profile or contour-markers) of biting-mechanisms)

Langlois, N. E. I., Greshham, G. A. (1991) The Aging of Bruises: A Review and Study of the Colour Change over Time *Forensic Science International* 1991; 50: 227-238  
(Experiment, characteristic (colour) of skinmark for diagnosing age of healing-process, reliability commented (colour is not sufficient on its own))

Kibayashi, K., Higashi, T., Tsunerari, S. (1991) A Differential Study Between Antemortem Bleeding and a Post-mortem Infiltration of Hemoglobin *Jpn. J. Leg. Med.* 1991; 45: 227-232  
(Experiment, characteristics (antemortem bleeding/Postmortem infiltration of haemoglobin by immunological methods) for diagnosing age of healing process, reliability assessment formal)

Averill, D. C. (ed) (1991) *Manual of Forensic Odontology* ASFS, 1991  
(Descriptive, introductory/manual forensic odontology general)

Dailey, J. C. (1991) Transparent Bite Mark Overlays, in Averill D.C. (ed) (1991) *Manual of Forensic Odontology* ASFS, 1991  
(Descriptive, introduction/manual, bma)

Pierce, L. J. (1991) Early history of Bite Marks in Averill D.C. (ed) (1991) *Manual of Forensic Odontology* ASFS, 1991  
(History of bma)

*Wilhoit v. State of Oklahoma* 809 P.2d 1322 (Okl. Cr.1991)  
(Legal case)

## 1992

Keiser-Nielsen, S. (1992) *Teeth that told Denmark*: Odense University Press 1992  
(Descriptive, general forensic odontology)

Robinson, E., Wentzel, J., (1992) Toneline bite mark photography *J Forensic Sci* 37(1):195-207  
(descriptive, instrument ("toneline-photography) for observing characteristics (edges/contour/shape) of skinmarks and biting-mechanisms for diagnosing individual causal biting-mechanism, (informal and incomparable reliability assessment))

Kibayashi, K., Higashi, T., Tsunerari, S. (1992) Purification of Glycophorins of Erythrocyte membrane and Characterisation of Anti-human Glocophorin Serum *Kumano Med. J.* 1992; 43: 127-138  
(Descriptive, instrument (immunological) for observing characteristic (glycophorin) of skinmarks immunological method) for diagnosing age of healing process, comparability/repeatability unknown.)

Tsunerari, S., Kibayashi, K., Higashi, T. (1992) Differentiation Between Ante-mortem Bleeding and Post-mortem Infiltration of haemoglobin pigments *Med. Sci. Law* 1992; 32: 47  
(Experimental, characteristic (bleeding or haemoglobin pigment infiltration) of skinmark for diagnosing ante or post-mortem occurrence of skin injury, reliability assessment unknown, comparability unknown)

Weigler, S. (1992) Bitemark Evidence: Forensic odontology and the *Law Health Matrix: Journal of Law-Medicine* 1992:303-323  
(Descriptive, legal needs, forensic odontology general)

Porfilio, L. (1992) Bite Mark Evidence Contributes to the Criminal Justice System *WDA J.* 1992; 68(4, April):209-13, 236.  
(Descriptive, legal needs, bma-general)

Giannelli, P. C. (1992) Forensic Science: Dental and Bite Mark Evidence NCJ 136689  
*Criminal Law Bulletin* 1992:28:3: May-June:276-284  
(Descriptive, legal needs, forensic odontology general)

Hein, P. M., Pannenbecker, J., Schulz, E. (1992) Bite injuries upon a newborn *International Journal of Legal Medicine* 1992:105(1) January  
(Case-study, diagnosing adult or child)

Whatmough, L. N., Nuckles, D. B. (1992) Bite mark evidence: Increasing acceptance with a qualified expert witness American board of Forensic Odontology, *Legal Medicine*, 1992: 49-78  
(Descriptive, legal needs, bma-general, reliability)

West, M. H., Barsley, R. E. Frair, J., Stewart, W. (1992) Ultraviolet Radiation and its Role in Wound Pattern Documentation *Journal of Forensic Sciences* 1992; 37 (6, November): 1466-1479  
(Descriptive, instrument (UV-photo) for diagnosing presence of skinmark, reliability assessment unknown, comparability unknown)

Ginelli, F. (1992) Wound Repair, Keratinocyte, Activation and Integrin Modulation *J. Cell Sci* 1992; 101:1-5 (Experimental, Conceptual, characteristics (Keratinocyte, Activation and Integrin Modulation) for diagnosing age of skinmark, reliability assessment unknown, comparability unknown)

West, M. H., et al. (1992) The Detection and Documentation of Trace Wound Pattern by use of Alternative Light source *Journal of Forensic Sciences* 1992; 37 (6, November): 1480-1488  
(Descriptive, instrument (Alternative Light Imaging) for determining presence of skinmarks, reliability assessment informal, not comparable)

Ciaparelli, L., Hughes, P. (1992) Bite Marks in Tissue and in Inanimate Objects: Analysis and Comparison, in Clark, D.H. (ed) *Practical Forensic Odontology* , Wright 1992: 149-177  
(Experimental, methodological)

Brown, K. A. (1992) *Comparative bite marks: Differential diagnosis. Practical Forensic Odontology*, Wright 1992  
 (Descriptive, characteristics (unspecified) of skinmarks for diagnosing class and individual biting-mechanism, reliability assessment informal, low comparability)

Clark, D. H. (ed) (1992) *Practical Forensic Odontology*, Wright 1992  
 (Descriptive, introductory/manual, FO-general)

Summers, R., Lewin, D. Forensic dental photography in Clark, D.H. (ed) (1992) *Practical Forensic Odontology*, Wright 1992: 188-205  
 (Descriptive, instrument (photography) for observing characteristics (unspecified) of skinmarks or biting-mechanism, reliability assessment informal/absent comparability low)

Clark, D. H. (1992) *Bitemark examination procedure: victims and suspects* Oxford: Butterworth Heineman Ltd. 1992  
 (Descriptive, introductory/manual, bma-general)

Gerrard, J. M., Duta, E., Nosek-Cenkowska, B., Singhroy, S., Cheang, M., Kobrinsky, N. L. (1992) A Role for Prostacyclin in Bruising Symptomatology *Pediatrics* 1992; 90(1): 33-36  
 (Experiment, characteristic (Prostacycline) of skinmark for diagnosing stage of bruising in skinmark, reliability assessment unknown, not bma-related)

## 1993

Mailis, N. P. (1993) Bitemarks in forensic dental practice: the Russian experience *J Forensic Odont* 1992: 11(1):31-3  
 (History, Russia)

Juhasz, I., Murphy, G. F., Yan, H. C., Herlyn, M., Albelda, S. M. (1992) Regulation of Extracellular Matrix Proteins and Integrin Cell Substratum Adhesion Receptors on Epithelium During Cutaneos Human Wound Healing in Vivo *Am. J. Pathol.* 1993; 143: 1458-1469  
 (Experimental, characteristics (extracellular matrix proteins and integrin cell substratum adhesion receptors on epithelium) of skinmarks for diagnosing stage of healing in skininjury, reliability assessment unknown)

Kiayashi, K., Honjyo, K., Higashi, T., Tsunemari, S. (1993) Differentiation of Discoloration in a Body by an Erytrocite Membrane Component, Glycophorin A *Ann. Acad. Med. Singapore* 1993; 22(1). 28-32  
 (Experiment, characteristic (Glucophorin A in Erytrocite membrane) of skinmark for diagnosing antemortem bruising or post-mortem hemolysis, reliability assessment informal/not comparable)

Kibayashi, K., Hamada, K., Honjyo, K., Tsunemari, S. (1993) Differentiation between Bruises and Putrefactive Discoloration of The Skin by Immunological Analysis of Glycophorin A *Forensic Science International* 1993: 61: 111-117  
 (Experiment, characteristics (Glucophorin A in Erytrocite membrane) of skinmark

for diagnosing antemortem bruising or post-mortem hemolysis, reliability assessment not known)

Figgener, L., (1993) Points of contact between quality issues and forensic aspects *J Forensic Odont*; 11(2):71-5  
(Descriptive, methodology, legal needs, forensic odontology general)

Krauss, T. C. (1993) Forensic Evidence documentation using reflective ultraviolet photography *Photo Electronic Imaging* 1993; 12(2): 18-23  
(Descriptive, instrument (RUV-photo) for observing characteristics (unspecified) of skinmarks and biting-mechanisms for diagnosing class and individual object/mechanism reliability assessment unknown)

LeRoy, H., Sweet, D. (1993) Human Bitemarks: Victim evidence recognition and recovery, NCJ 141909, *Royal Canadian Mounted Police Gazette* 1993:55(3): 4-7  
(Descriptive, introductory/manual, BMA-general)

LeRoy, H., Sweet, D. (1993) Taking a Bite out of Crime: Ask a Forensic Dentist for assistance, NCJ 141908, *Royal Canadian Mounted Police Gazette* 1993:55(3):1-3  
(Descriptive, introductory/manual, BMA-general)

Grodsky, M. (1993) Bite mark Identification: A technique for Instructors NCJ 142938 *Journal of Forensic Identification* 1992:43(3):(May/June): 248-252  
(Descriptive, introductory/manual, BMA-general)

Phillips, V. M. (1993) The role of forensic dentistry in South Africa *Med Law* 1993;12(6-8):487-91.  
(Descriptive, introductory/manual, BMA-general (SouthAfrica))

Gianelli, P. C. (1993) Junk Science: The Criminal Cases *Journal of Criminal Law and Criminology* 1993-1994; 84(1): 105-128  
(Descriptive, legal needs, reliability; Daubert is better than FRE75-702, case (Washington v. State (1992) and Harrison v. State (unknown date))

## 1994

American Board of Forensic Odontology (1994) *Workbook ABFO Bitemark Workshop* #2 San Antonio: Texas, 1994 (February 12-14)  
(Normative (ABFO-guidelines), bma)

Ligthelm, A. J, van Niekerk, P.J. (1994) Comparative review of bitemark cases from Pretoria, South Africa. *J Forensic Odont* ; 12(2):23-9  
(History, review of bitemark-cases Pretoria South Africa)

Wood, R. E., Miller, P. A., Blenkinsop, B. R. (1994) Image editing and computer assisted bitemark analysis: a case report. *J Forensic Odontostomatolgy* 1994; 12(2):30-6  
(Case-study)

Thompson, I. O., Phillips, V. M. (1994) A bitemark case with a twist *J Forensic Odont* 1994: 12(2):37-40  
(Case-study, false positive)

Jessee, S. A. (1994) Recognition of bite marks in child abuse cases *Paediatric Dentistry* 1994:16(5):336-9  
(Descriptive, introduction/manual, BMA for health-professional as signs of abuse)

Barry, L. A. (1994) Bite mark evidence collection in the United States *Bull Hist Dent* 1994: 42(1):21-7  
(Descriptive, partial review)

Nuckles, D. B., Herschaft, E. E., Whatmough, L. N. (1994) Forensic odontology in solving crimes: dental techniques and bite-mark evidence *General Dentistry* 1994:42(3):210-4  
(Descriptive, review, introductory/manual, BMA-general)

Rothwell, B. R. (1994) Bite marks in forensic odontology: Fact or Fiction, in Worthington, P., Evans, J.R. (ed) (1994): *Controversies in Oral and Maxillofacial Surgery*, Philadelphia: WB Saunders, 588-600  
(Descriptive, review, introductory/manual, BMA-general)

French, G. M., Johnson, C. F. (1994) Bites in the night: Determining the etiology of bite marks on an infant *Pediatr Emerg Care* 1994 Oct;10(5):281-3  
(Case-study)

David, T. J. (1994) Recapturing a Five-Month-Old Bite Mark by Means of Reflective Ultraviolet Photography *Journal of Forensic Sciences* 1994; 39(6) November: 1560-1567  
(Case-study, instrument (RUV-photo) for observing characteristic (unspecified) of skinmark for diagnosing presence of skinmark after five months)

Golden, G. S. (1994) Use of alternative light source illumination in bite mark photography. *J Forensic Sci* 1994 May;39(3):815-23.  
(Descriptive, instrument (Alternative Light Source) for observing characteristic (unspecified) of skinmark for diagnosing (unspecified))

Buser, L. W. (1994) Death Row: Victor J. Cazes NCJ 152123 *Police: The Law Enforcement Magazine* 1994:18(9)(September):62-66  
(Case-study)

Starrs, J. E. (1994) Bitemarks in the courts, a review of 1994's appellate court decisions *Scientific Sleuthing Rev.* 1994;18(4): 1-5  
(Descriptive, review of BM-cases appellate courts USA)

*Milone v. Camp*, 22 F.3d 693 (7th Cir 1994)  
(Legal case)

*State v. Hodgson*, 512 N.W. 2d 95 (Minn. 1994)  
(Legal case)

## 1995

ABFO *Bite-Mark Methodology Guidelines* 1995  
(Normative, ABFO-guidelines, bma)

ABFO *Bitemark Terminology Guidelines* 1995  
(Normative, ABFO-guidelines, bma)

Jakobsen, J., Holmer, L., Fredebo, L., Sejrsen, B. (1995) Scanning electron microscopy, a useful tool in forensic dental work, *J. Forensic Odontostomatol.* 1995;13:36-40  
(Descriptive, instrument (scanning electron microscope) for observing characteristics (unspecified) of skinmarks and biting-mechanisms for various forensic purposes)

McKinstry, R. E. (1995) Resin Dental Casts As an Aid in Bite Mark Identification *Journal of Forensic Sciences*, 1995, 40(2):300-302  
(Descriptive, instrument/material (resin dental casts) for preserving or representing characteristics (unspecified) of biting-mechanisms, reliability assessment informal/not comparable)

Nambiar, P., Bridges, T. E., Brown, K. A. (1995 a) Quantitative Forensic Evaluation of Bite Marks with the Aid of a Shape Analysis Computer Program. Part 1. The development of "SCIP" and the Similarity Index. *J Forensic Odontostomatology* 1995; 13: 18-25  
(Experimental, instrument (SCIP-index) for observing characteristic (similarity) of characteristics (morphological (shape, position) of skinmarks and biting-mechanisms for various forensic purposes)

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(Experimental, instrument (SCIP-index) for observing characteristic (similarity) of characteristics (morphological (shape, position) of skinmarks and biting-mechanisms for various forensic purposes)

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(Experiment, characteristic (incisor crown size) of teeth/biting- mechanisms, not bma-related, reliability assessment unknown)

Spencer, D. E. (1995) *Bite Marks in Child Abuse Manual of Forensic Odontology*, 3rd ed. Printing Specialists, 1995  
(Descriptive, introduction/manual, bma)

Bowers, M. (1995) The Visual Aging of Bitemarks, Beyond the Pale of Forensic Odontology *News of the American Board of Forensic Odontology* 1995; 3(1): 9-12  
(Descriptive, characteristics (unspecified) for diagnosing the age of bitemarks)

Betz, P. (1995) Immunochemical Parameters for the Age Estimation of Human Skin Wounds: A review *Am J Forensic Med Pathol* 1995; 16:203-239  
 (Review of knowledge of characteristics (different) of skinmarks for diagnosing age of skin-injury)

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 (Descriptive, characteristics (biomechanical) of human skin, not bma-related)

Bowers, C., Bell, G. (1995) *Manual of Forensic Odontology* Colorado springs, Co: American Society for Odontology; 3rd ed. 1995  
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Sweet, D. (1995) Human Bitemarks: Examination, Recovery and Analysis, in Bowers, C., Bell, G. (ed) *Manual of Forensic Odontology* Colorado springs, Co: American Society for Odontology; 1995: 148-170  
 (Descriptive, introductory/manual, bma-general)

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 (Review of characteristics (various) of skinmarks for diagnosing dog, cat, or human teeth)

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 (Descriptive, legal needs, BMA)

Sampson, W. J. (1995) Current Controversies in Late Incisor Crowding *Acad Med Singapore* 1995; 24: 129-137  
 (Review characteristic (late incisor crowding) of teeth/biting- mechanism, not bma-related)

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Whittaker, D. K. (1995) Teeth as weapons or witness *Science and Public Affairs* 1995  
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 (Descriptive, introductory/manual, bma)

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 (Descriptive, investigative/legal needs)

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 (Descriptive, introductory/manual BMA-general)

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(Experiment, longitudinal study of characteristics (tooth retention and tooth loss) of biting-mechanisms in permanent dentition adults USA, not bma-related)

Naru, A. S., Dykes, E., (1996) The use of a digital imaging technique to aid bite mark analysis. *Science & Justice*. 36(1):47-50  
(Description, instrument (computer-software) for producing instrument (transparent overlay) for observing characteristics (biting-edge contour) of biting-mechanisms)

Abour, M. A., O'Neill, P. J., Setchell, D. J., Pearson, G.J. (1996) Physical Properties of Casts Prepared From Disinfected Alginate *Eur J Prosthodont Restor Dent* 1996; 4(2): 87-91  
(Descriptive, instrument/material (Disinfected alginate base of casts) for preserving/representing characteristics of biting-mechanisms)

Bowers, C.M. (1996) A statement why court Opinions on Bitemark analysis should be limited *American Board of Forensic Odontology Newsletter* 1996; 4(2): 5  
(Normative, bma-reliability, individual))

Schwartz, A.J., Ricci, L.R. (1995) How Accurately can Bruises be Aged in Abused Children? Literature Review and Synthesis *Pediatrics* 1996; 97: 254-257  
(Review of accuracy of characteristics (various) of skinmarks for diagnosing age of bruising, not bma-related)

Betz, P., Eisenmenger, W. (1996) Morphometrical Analysis of Hemosiderin Deposits in relation to Wound Age *Int J Legal Med* 1996; 108: 262-264  
(Experiment, instrument (morphometric analysis) for observing characteristic (Hemosiderin Deposit) of skinmark marker for diagnosing age of wound, reliability assessment unknown)

Oehmichen, M., Kirchner, H. (eds) (1996) *The wound Healing Process: Forensic Aspects* Lubeck: Schmidt Romhild 1996  
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(Experiment, instrument (spectrometry) for observing characteristic (various) of skinmarks for diagnosing age of skinmark (haematoma))

Christiensen, H., Alder, M. E. (1996) Generating Transparent Bite Mark Overlays Using a Scanner, Microcomputer and Laser Printer *Proceedings of the American Academy of Forensic Sciences* 1996; 2: 118

(Descriptive, instruments (scanner, microcomputer, laserprinter) for producing instrument (transparent overlay) for observing characteristics (cutting edge/contour) of biting-mechanisms) for diagnosing class and individual biting-mechanism)

Dorion, R. B. J. *Forensic Dentistry in Quebec from 1973 to 1995* *JCSFS* 1996; 29(4):259-268  
 (History of BMA Quebec 1973-1975)

Naru, A. S., Dykes, E. (1999) Digital Image cross correlation technique for bite mark investigations *Science and Justice* , 1997;37(4):251-258  
 (Descriptive instrument (digital image cross correlation) for observing characteristics (metric) of skinmarks and biting-mechanisms)

Sweet, D., LeRoy, H. A. (1996) Human Bitemarks: Recovery of Forensic Evidence for Suspects *NCJ 163755 Gazette* 1996:58(4) (April):2-7  
 (Descriptive, introduction/manual, legal needs (suspect's rights))

Vale, G. L. (1996) Dentistry, bite marks and the investigation of crime *J Cal Dent Assoc* 1996: 24(5):29-34  
 (Descriptive, introduction/manual, BMA-general)

Suzuki, K. (1996) The history of forensic odontology in Japan *Forensic Science International* 1996;80(2): 33 - 38  
 (History of forensic odontology Japan)

Aksu, M. N., Gobetti, J. P. (1996) The past and present legal weight of bite marks as evidence. *Am J Forensic Med Pathol* ; 17(2):136-40  
 (Descriptive, legal needs, reliability commented)

Vieira, D. N. (1996) Application of Ions, Proteinase Inhibitors and PGF2a in the Differential Diagnosis between Vital and Postmortem Skin Wounds *International Journal of legal medicine* 1996;116(2):109-112  
 (Experimental, characteristics (apoptosis (apop-tag-method)) of skinmarks for diagnosing age of skinmark (occurrence - signal-traffic stop), reliability assessed formally and informally (by stressing the control of performance of apop-tag and by stressing the need for complementary methods (such as necrotic markers)))

Oehmichen, M., Kirchner, H. (eds) (1996) *The Wound healing Process: Forensic Pathological Aspects* Schmidt-Rmhild, Lbeck 1996: 83-106  
 (Descriptive, wound healing generally for estimating time injury-death)

Norrlander, A. L. (1996) Comment on Aksu et al.'s "the past and present legal weight of bite marks as evidence" 1996. *The American Journal of Forensic Medicine and Pathology* 1996;17(4)(Dec):352-4.  
 (Descriptive, comment to Aksu and Gobetti (1996))

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(Descriptive, instrument (morphometrics) for observing characteristics of forensic samples (not related to bma))

American Board of Forensic Odontology (1997) *Workbook ABFO Bitemark Workshop #3* New York, NY, 1997 (Feb 16-17)  
 (Normative, ABFO-guidelines 1997, bma)

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 (Descriptive, introduction/manual FO-general)

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 (Descriptive, introduction/manual BMA-general)

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 (Descriptive, preserving/representing characteristics (unspecified) of skinmark)

Betz, P., Nerlich, A., Tubel, J., Wiest, I., Hausmann, R. Detection of Cell Death in Human Skin Wounds of Various Ages by an in Situ end Labelling of Nuclear DNA-fragments *Int J. Legal Med* 1997; 110: 240-243  
 (Experiment, instrument (staining-method) for observing characteristics (DNA-fragments targeting apoptotic cells) of skinmarks on human skin for diagnosing age of apoptotic process (time between injury and signal-stop))

Naru, A. S. (1997) Methods for the analysis of Human Bite Marks *Forensic Science Review* 1997:9:123-139  
 (Review of degree of consensus on methodology and instruments in bma)

Naru, A., Dykes, E. (1997) Digital Image Cross-correlation Technique for Bite Mark Investigations *Sci. Justice* 1997; 37(4):251-258  
 (Experimental, instrument (cross-correlation techn) for observing characteristic (similarity) of characteristics (various) of skinmarks and biting-mechanisms for various diagnostic forensic purposes.)

Dailey, J. C., Bowers,C. M. (1997) Aging of Bitemarks: A Literature Review *Journal of Forensic Sciences*, 1997;42(5):792-795.  
 (Review of instruments and characteristics observed for diagnosing age of bitemark)

Gray-Ray, P., Hensley, C., Brennan, E. (1997) Violent rape and bite marks: the use of forensic odontology and ultraviolet lighting *Policing: An International Journal of Police Strategies & Management* 1997;20(2):223-234  
 (Descriptive, introductory/manual, BMA-general for the crime investigator)

Whittaker, D. K., Aitken, M., Burfitt, E., Sibert, J. R. (1997) Assessing bite marks in children: working with a forensic dentist. *Ambulatory Child Health* 1997;3(3):225-229  
 (Descriptive, introductory/manual, BMA-general for health-personnel)

Oliver, W. R., Boxwala, A., Rosenman, J., Cullip, T., Symon, J., Wagner, G. (1997) Three-dimensional visualisation and image processing in the evaluation of patterned injuries. The AFIP/UNC experience in the Rodney King Case *Am J Forensic Med Pathol* 1997; 18(1):1-10  
(Descriptive, instrument (3D-imaging) for observing characteristics of skinmarks and biting-mechanisms )

Sweet, D. (1997) *Computer Assisted 2D and 3D Comparisons of Bite Mark Evidence and Tooth Exemplars* Canadian Police Report Centre, Technical Report, September, 1997  
(Experiment, instrument (5 different) for producing instrument (transparent overlays) for observing characteristics (biting-edge-profiel) of biting-mechanisms markers for diagnosing calss and individual biting-mechanism)

Sweet, D. (1997) *Incidence of Human Bite Marks in a Selected Adult Population* Canadian Police Report Centre, Technical Report, September, 1997  
(Epidemiological, prevalence of BM in Canadian domestic violence injury Database)

Sweet, D. J., Parhar, M. (1997) Computer-based Production of Bite Mark Comparison Overlays. *Proceedings of the American Academy of Forensic Sciences* 1997; 3: 113  
(Descriptive, instrument (3D-photoshop) for producing instrument (transparent overlays) for observing characteristics of teeth/- biting-mechanisms for various forensic purposes)

Stimson, P. G., Mertz, C. A. (eds.) *Forensic Dentistry* CRC Press 1997 (Descriptive, introductory/manual, FO-general)

Duarte, A..M. M. D., Garzon, M. C. M. D., Laude, T. A. M., Sigfried, E. (1997) *Proceedings of the Society for Pediatric Dermatology* Meeting, Manchester Village August 8 Pediatric Dermatology 1997 Vol ?  
(Descriptive, introductory/manual, forensic bma-general for health-personnel)

Donnelly, W. J., Ciccone, R. (1997) Excluding a Suspect Using Bite-Mark Evidence *Journal of forensic Identification* 1997;47(3):264-273  
(Case-study, true/false negative, suspect population))

*Howard v. State*, 701 So.2d 274, 288 (Miss.1997)  
(Legal case)

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Bowers, C. M. (1998) The Scientific Basis for Bitemark Probability Determination ASFO News, 1998; summer: 14  
(Review of the scientific standard of bma.)

Delattre, V., Stimson, P. (1998) Bite Marks v. Other Injuries - Forensic Odontological Evaluation of a Homicide *Proceedings of the American Academy of the Forensic Sciences Annual Meeting*, San Fransisco, 1998  
(Case-study)

Sweet, D., Parhar, M., Wood, R.E., (1998) Computer-based production of bite mark comparison overlays *J Forensic Sci*; 43(5):1050-5  
 (Descriptive, instrument (computer software) for producing instrument (hollow overlays) for observing characteristics (edge-profile, mark-areas) of biting-mechanisms for diagnosing class and individual biting-mechanism)

Baccetti, T. (1998) Tooth Rotation Associated with Aplasia of Nonadjacent Teeth Angle *Ortod* 1998; 68: 471-474  
 (Experiment, characteristic (tooth-rotation of nonadjacent teeth, given Aplasia-condition) of biting-mechanisms, not bma-related)

Whittaker, D. K., Brickley, M. R., Evans, L. (1998) A comparison of the ability of experts and non-experts to differentiate between adult and child bite marks using receiver operating characteristics *Forensic Science International* 1998; 92: 11-20  
 (Experiment, characteristic (reliability) of instrument (bma-expert) when diagnosing natural bitemarks on human skin to be by adult or child natural biting-mechanism)

al-Omari, W. M., Jones, J. C., Wood, D. J. (1998) The Effect of Disinfecting Alginate and Addition Cured Silicone Rubber Impression Materials on the Physical Properties of Impressions and Resultant Casts *Eur J Prosthodont Restor Dent* 1998; 6(3): 103-110 (Experiment, instrument/material (Disinfecting Alginate and Addition Cured Silicone Rubber Impression Materials) for producing instrument (Impressions and Casts) for preserving/representing characteristics (unspecified) biting-mechanisms for dental health-purposes, reliability of secondary material central, reliability assessment formal/comparable, not related to bma)

Dhar, V., Tandon, S. (1998) Bite Mark Analysis in Child Abuse *J Indian Soc Pedodon Preve Dent* 1998; 16(3): 96-102  
 (Descriptive, introductory/manual, BMA-general for health-personnel (abuse-context))

Doubleday, B. (1998) Impression Materials *Br J Orthod* 1998; 25(2): 133-140  
 (Review of instruments/material (various) (for preserving/representing biting-mechanisms), not forensic or bma (but health-oriented))

Sweet, D., Bowers, C. M. (1998) Accuracy of bite mark overlays: a comparison of five common methods to produce exemplars from a suspect's dentition *J Forensic Sci*; 43(2):362-7  
 (Experimental, characteristic (reliability) of instruments (expert plus five techniques of overlays-production) for observing characteristics (cutting-edge profile, area, tooth rotation) of biting-mechanisms (casts)).

Atsu, S. S., Gokdemir, K., Kedici, P. S., Ikvaz, Y. Y. (1998) Bitemarks in forensic odontology. *J Forensic Odontostomatol* 1998 Dec;16(2):30-4.  
 (Descriptive, instrument (computer software) for observing characteristics (unspecified) of bitemarks in wax and in human skin)

DeLattre, V., Stimson, P. G. (1998) Bite Marks vs. Other Injuries- Forensic Odontological. Evaluation of a Homicide. *Proceedings of the American Academy of Forensic Sciences*, 1998,  
(Descriptive, characteristics (various) for diagnosing human teeth or other)

Wright, F. D. (1998) Photography in bite mark and patterned injury documentation - Part 1. *J Forensic Sci* 1998 Jul;43(4):877-880  
(Descriptive, instrument (light/photo) for observing characteristics (unspecified) of skinmarks for diagnosing occurrence/non-occurrence of impact)

Wright, F. D. (1998) Photography in bite mark and patterned injury documentation - Part 2: A case study. *J Forensic Sci* 1998 Jul;43(4):881-7  
(Case-study)

Sweet, D. (1998) Radiographic Techniques in Bite Mark Analysis - Identification of the Perpetrator, in Brogdon, B.G. (1998) *Forensic Radiology* (Chapter 7., 10 pages) ISBN 0849381053, 9780849381058  
(Descriptive, instrument (radiography) for observing characteristics (unspecified) of skinmarks for diagnosing class and individual biting-mechanisms)

Saks, M. J. (1998) Merlin and Solomon: Lessons from. the law's formative encounters with forensic. identification science, *Hastings Law Journal* 1998;?  
(Legal needs, Forensic general, BMA-reliability commented)

## 1999

American Board of Forensic Odontology (1998) Workbook ABFO Bitemark Workshop #4 Orlando, FL. 1999 (Feb 14-15)  
(Normative, ABFO-guidelines 1998, bma)

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(Experimental, instrument (computer software) for observing characteristics (metric) of skinmarks and biting-mechanisms for forensic purposes)

Kim, J. J., Sweet, D. (1999) Evaluation of Use of ABFO Bitemark Guidelines in Various Geographic Locations *Proceedings American Academy of Forensic Sciences Annual Scientific Meeting* San Francisco, 1999. Proceedings.  
(Experimental, survey of regional expert adherence to ABFO-norms for BMA-purposes)

Tsang, A., Sweet, D., Wood, R. (1999) Potential for Fraudulent use of Digital Radiography *J Am Dent Assoc* 1999; 130(9): 1325-1329  
(Descriptive, legal needs)

Dorion, R. B. J. (1999) *Bite Mark Recovery, Preservation, and Forensic Aspects of Physical Evidence* Council on Dental Practice ADA, Chicago, March 26, 1999  
(Descriptive, introductory/manual, BMA-general)

Dorion, R. B. J. (1999) *Bite Marks in Life and Death. Detection and Recovery of Human Remains* FBI, Child Abduction and Serial Killer Unit, Evidence Recovery Team, Quantico May 21, 1999  
 (Descriptive, introductory/manual, FO-general and BMA-general, investigative needs)

Dorion, R. B. J. (1999) *Forensic Dentistry Overview and Bite Mark Evidence* Regional Organised Crime Information Center. Lexington, KY June 1999  
 (Descriptive, introductory/manual, FO-general and BMA-general, investigative needs)

Brzozowski, C. C., Nawrocki, L. A., Friedman, B. K. (1999) *A Comparison of Dimensional Stability of Excised Patterned Injuries Using Various Fixatives: A Preliminary Study* AAFS meeting, odontology section, Feb 1999  
 (Experimental, instrument (excision-technique) and material (preserving liquids/fixatives) for preserving/representing characteristics (various) of skinmarks)

Johansen, R. J., Bowers, C. M. (1999) *Digital Analysis of Bite Mark Evidence* Forensic Imaging Service, Santa Barbara, CA(1999)  
 (Descriptive, introductory/manual, instrument (computer software))

Vale, G. L., Anselmo, J. A. (1999) *Forensics of Human Bite Wounds* Forensic Emergency Medicine, Part I Topics in Emergency Medicine *Advanced Emergency Nursing Journal* 1999;21(3):11-20  
 (Descriptive, introductory/manual for BMA for health-personnel)

McKenna, C. J., Haron, M. I., Taylor, J. A. (1999) Evaluation of a Bitemark Using Clear Acrylic Replicas of the Suspect Dentition - a Case Report *J Forensic Odontostomatology* 1999; 17(2, Dec): 40-43  
 (Case-study, instrument/material (acrylic replica) for preserving/representing characteristics (various) of biting-mechanisms)

American Academy of pediatric dentistry Committee on Child Abuse and Neglect and Ad Hoc Work Group on Child Abuse and Neglect, joint statement (1999) Oral and Dental Aspects of Child Abuse and Neglect *Pediatrics* 1999;104 (2): 348-350  
 (Descriptive, introductory/manual for BMA for health-personnel)

Alt, K. W., Waltz, M. (1999) Dental Print Media and their Value in Forensic Odontology *J Forens Odontostomatol* 1999; 17(1): 5-9  
 (Descriptive, instrument (Dental Print Media) for observing characteristics of biting-mechanisms)

Hancock, S. (1999) The last romance *British Dental Journal* (News and Notes, view from the chair) 1999;186(12):650  
 (Descriptive, legal needs, BMA-general)

Vexler, A., Polyansky, I., Gorodetsky, R. (1999) Evaluation of Skin Viscoelasticity and Anisotropy by Measurement of Speed of Shear Wave Propagation with Viscoelasticity Skin Analayser 1 *J. Invest. Dermatology* 1999; 113: 732-739 (Experiment, in-

strument (Viscoelasticity Skin Analayser 1) for observing characteristics (viscoelasticity and anisotropy (by measuring speed of shear wave propagation)) of human skin, not related to bma)

Broeders, A. P. A. (1999) Some observations on the use of probability scales in forensic in forensic identification *Forensic Linguistics* 1999; ?: 228-241  
(Descriptive, instrument (probability) for observing characteristic (certainty) of characteristic (confidence) in forensic diagnosis, not bma-related)

Levine, M. (1999) "The legal Culture must Assimilate the Scientific Culture" and Vice Versa? Review of Faigman, D., Kaye, D., Saks, M., Sanders, *J. Law & Policy* 1999;21(1)(January): 77-90(14)  
(Review of Saks et al (1999) "Modern scientific evidence", methodology, legal needs)

Imwinkelried, E. J. (1999) Should the Courts Incorporate a Best Evidence Rule into the Standard Determining the Admissibility of Scientific Testimony: Enough is Enough Even When It Is Not the Best *Case W. Res. L. Rev.* 1999-2000; 50:19-51  
(descriptive Legal needs (reliable evidence))

Faigman, D. L., Kaye, D. H., Saks, M. J., Sanders, J. (1999) How Good is Good Enough: Expert Evidence under Daubert and Kumho Reply Essay *Case Western Reserve Law Review* 1999/2000;50:648-667  
(Descriptive, legal needs (reliable evidence))

## 2000

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(Descriptive, instrument (probability) for observing characteristic (certainty) of characteristic (confidence) in forensic diagnosis, not bma-related)

Rawson, R. B., Starich, H. G., Rawson, R.D. (2000) Scanning Electron Microscopic Analysis of Skin Resolution as an Aid in Identifying Trauma in Forensic Investigations *J. Forensic Sci* 2000; 45(5): 1023-1027  
(Experiment, instrument (scanning electron microscopy) for observing characteristic (various) of skinmarks for various forensic purposes, not bma-related)

Ouhtit, A., Muller, H. K., Davis, D. W., Ullrich, S. H., McConkey, D., Ananthaswamy, H.N. (2000) Temporal Events in Skin Injury and the Early Adaptive Responses in Ultraviolet-irradiated Mouse Skin *Am. J. Pathol.* 2000, 156:201-207  
(Experiment, instrument (UV-radiation) for observing characteristics (various) of skinmarks for diagnosing age of skinmark)

Robinson, D. L., Blackwell, P. G., Stillman, E. C., Brook, A. H. (2000) Planar Procrustes Analysis of Tooth Shape *Arch Oral Biol* 2001; 46:191-199  
(Experiment, instrument (planar procrustes analysis) for observing characteristic (tooth-shape) of biting-mechanisms for dental health purposes, not bma-related)

Sato, Y., Ohsima, T. (2000) The Expression of mRNA of Proinflammatory cytokines during Skin Wound Healing in Mice: A Preliminary Study for Forensic Wound Age Estimation *Int J. Legal Medicine* 2000; 113: 140-145  
 (Experiment, characteristic (expression of mRNA of proinflammatory cytokines) of skinmarks (mice) for diagnosing age of skinmark)

Ritz-Timme, S., Cattaneo, C., Collins, M.J., Waite, E.R., Schutz, H.W., Kaatsch, H.J., Borrman, H.I.M. (2000) Age Estimation: The State of the Art in Relation to The Specific Demands of Forensic Practice *Int J. Legal Medicine* 2000; 113: 129-136  
 (Review of knowledge of characteristics (various) of skinmarks for diagnosing age of skinmark)

Pretty, I.A. (2000) *Bitemark Overlays - An analysis of Effectiveness* University of British Columbia 2000; March. (Master thesis)  
 (Experiment, characteristic (reliability) of instrument (expert and overlay) for observing characteristic (similarity/difference) of characteristics (various) of skinmarks (simulated, post-mortem pigskin) and biting-mechanisms (casts))

Pretty, I.A., Sweet, D.A. (2000) A Comprehensive Examination of Bitemark Evidence in the American Legal System *Proceedings of the American Academy of Forensic Science*, Reno NV 2000; 6: 146  
 (Review of legal cases USA)

El-Mehallawi, I. H., Saudi, H. (2000) Computer-based Methods for accurate Bite Mark Analysis *Mansoura J. of Forensic Medicine and Clinical T.* 2000; ?: ?  
 (Descriptive, review of instruments (computer-based) for observing characteristics (unspecified) of biting-mechanisms (Not able to locate))

Johansen, R. J., Bowers, C. M. (2000) *Digital Analysis of Bite Mark Evidence* Santa Barbara, CA: Forensic Imaging Services 2000  
 (Descriptive, instruments (computer-software) for observing characteristics (various) of skinmarks and biting-mechanisms; Book is reviewed by Kenney, J.P. J (2002), *Forensic Sci* 2002; 47(3): 709)

Pretty, I. A., Sweet, D. (2000) Anatomical Location of Bitemarks and Associated Findings in 101 Cases from the United States *J. Forensic Sciences* 2000; 45(4): 812-814  
 (Epidemiological, prevalence of bitemarks in court cases in USA (by bodypart, gender, kind of crime, number of bitemarks pr. person))

Webb, D. A., Pretty, I. A., Sweet, D. (2000) Bitemarks: A Psychological Approach *Proceedings of the American Academy of Forensic Sciences* Reno, NV, 2000; 6(February): 147  
 (Descriptive, motive of biting behaviour)

Pitluck, H. (2000) Bitemark Citations. *Bite Mark Management and Legal Update* Las Vegas, pitluck, 2000:1,2  
 (Descriptive, legal needs, introductory/manual BMA-general)

Brzozowski, C. C., Nawrocki, L. A., Friedman, B. K. (2000) *A Comparative Study of Materials and Methods used for Collection, Stabilising and preserving Excised Tissue* AAFS meeting odontology section, Reno, Feb. 26., 2000  
(Experiment, instruments/materials (various) for preserving/- representing tissue-samples, not bma-related)

Bell, K., Ledray, L. E. (2000) Identification and Documentation of Bite Marks *J Emerg Nurs.* 2000; 26: 628-630  
(Descriptive, introductory/manual BMA-general)

Sakoda, S., Fujita, M., Zhu, B., Oritani, S., Ishida, K. (2000) Wounding dynamics in distorted Bitemarks: Two Case Reports *J Journal of Forensic Odonto-Stomatology* 2000; 18: 46-51  
(Case-study)

## 2001

Sutherland, S. E. (2001) Evidence-based Dentistry: Part I. Getting Started *Can Dent Assoc* 2001; 67: 204-206  
(Normative, evidence-basis for dentistry, not related to bma)

Pretty, I. A., Turnbull, M. D. (2001) Lack of Dental Uniqueness Between Two Bite Mark Suspects *J Forensic Sci* 2001; 46(6): 1487-1491  
(Case-study)

Pretty, I. A., Sweet, D. (2001) The Scientific Basis for Human Bitemark Analysis - A Critical Review *Science and Justice Journal of the Forensic Science Society* 2001; 41: 85-92  
(Review of the scientific standard of bma)

Pretty, I. A., Sweet, D. (2001) Digital Bite Mark Overlays - An Analysis of Effectiveness *J. Forensic Science* 2001; 46 (6): 1385-1391  
(Experiment, characteristic (reliability) of instrument (expert and overlay) for observing characteristic (similarity/difference) of characteristics (various) of skinmarks (simulated, post-mortem pigskin) and biting-mechanisms (casts))

Pretty, I. A., Sweet, D. (2001) Adherence of Forensic Odontologists to the ABFO BiteMark Guidelines for Suspect Evidence Collection *J Forensic Sci* 2001; 46(5): 1152-1158  
(Epidemiological, prevalence of adherence to ABFO-guidelines)

Sweet, D. (2001) Why a Dentist for Identification? *Dent Clin orth Am* 2001; 45(2): 237-251  
(Descriptive, introductory/manual, FO general)

Karazulas, G. (2001) *New Forensic Odontology Tools* Connecticut State Police Forensic Science Lab, 2001, March 21  
(Descriptive, instrument (LUCIS (image enhancing software)) for observing characteristics (unspecified) of bitemarks and biting-mechanisms)

Sweet, D., Pretty, I. A. (2001) A look at Forensic Dentistry - Part 2: Teeth as Weapons of Violence - Identification of Bitemark Perpetrators *British Dental Journal* 2001; 190(8): 415-418  
 (Descriptive, introductory/manual, BMA general)

Karazalus, C. P. Palmbach, T.T., Lee, H. C. (2001) Digital Enhancement of Sub-Quality Bitemark Photographs *J Forensic Sci* 2001; 46(4): 954-958  
 (Descriptive, instrument (LUCIS (image enhancing software)) for observing characteristics (unspecified) of bitemarks and biting-mechanisms)

Vanezis, P. Interpreting Bruises at Necropsy (2001) *J. Clin. Pathol.* 2001; 548-355  
 (Review of instruments and characteristics for diagnosing age of bruises, not related to bma)

Giannelli, P. C. (2001) Scientific Evidence in the Sam Sheppard Case *Clev. St. L. Rev.* 2001; 49: 487-498  
 (Case-study, legal needs)

Clouser, J. (2001) Lighting by Bite Mark Photography *Journal of Forensic Identification* 2001; 51: 1-8  
 (Descriptive, instrument (light/photo) for observing characteristics (various) of bitemarks in human skin)

Low, B., Rothwell, B., Thien, A. (2001) Analysis of Distortion in Preserved Bite Mark Skin *Journal of Forensic Sciences* 2001; 46: 573-576  
 (Experiment, characteristic (reliability) of instrument/material (fixating liquid, unspecified) for preserving/representing characteristics (various) of bitemarks)

Bowers, C.M. (2001) Jurisprudence Issues in Forensic Odontology *Dent Clin North Amer.* 2001; 45(2): 399-415  
 (Descriptive, legal needs, FO-general)

Bowers, C. M., Johansen, R.J. (2001) Digital Rectification and Resizing Correction of Photographic Bite Mark Evidence *Forensic Science Communications* 2001; 3(3, July)  
 (Experiment, instrument (digital software) for correcting reliability of instrument (photography) for preserving/representing characteristics (various) of skinmarks and biting-mechanisms)

Bowers, C. M., Johansen, R. J. (2001) Digital Analysis of Bitemarks and Human Identification *Den Clin of North Am* 2001; 45(2): 327-342  
 (Description, instrument (digital software) for observing characteristics (various) of bitemarks and biting-mechanisms for remains-identification and for bma)

Bowers, C. M., Bell, G. L., eds (2001) *Manual of Forensic Odontology* (chapter: ABFO bite mark methodology guidelines) American Society of Forensic Odontology, Colorado Springd, Colorado, 3rd ed. 2001  
 (Descriptive, introductory/manual, FO/BMA general)

Wright, F. D. (2001) *The Trials and Tribulations of Bite Mark Analysis: Seeing What is Really There* AAFS Annual Meeting Seattle 2001  
(Descriptive, introductory/manual, BMA general)

Wright, F. D. Dailey, J. C. (2001) Human Bite Marks in Forensic Dentistry *Dent Clin North Am* 2001; 45(2, April): 365-397  
(Review of current knowledge of bitemarks)

Fixott, R. (2001) *Forensic Odontology Dental Clinic of North America* Saunders Philadelphia, 2001  
(Descriptive, introductory/manual, FO-general)

Dorion, R. B. J. (2001) *Pitfalls in Documenting and Preserving Bite Mark Evidence in Pediatric Deaths* American AAFS meeting odontology Section, Seattle, 2001  
(Review of instruments/materials and observations of characteristics of samples in bma)

Arheart, K. L., Pretty, I. A. (2001) Results of the 4th ABFO Bitemark Workshop 1999 *Forensic Science International* 2001; 124: 104-111  
(Experiment, characteristic (reliability) of instrument (expert) for observing characteristic (similarity/difference) of characteristics of bitemarks (3 natural in human skin and 1 simulated in cheese) and biting-mechanisms (casts)

Sheasby, D. R., MacDonald, D. G. (2001) A Forensic Classification of Distortion in Human Bite Marks *Forensic Science International* 2001; 122: 75-78  
(Descriptive, conceptualising characteristics (various) of intervening items between standard characteristics of biting-mechanisms and bitemarks)

Rothwell, B. R., Thien, A. V. (2001) Analysis of Distortion in Preserved Bite Mark Skin *J Forensic Sci* 2001; 46(3): 573-576  
(Experiment, characteristic (reliability) of instrument/material (formalin 10%) for preserving/representing skinmarks (on pigskin)

Forrest, A., Davies, I. (2001) Bite-marks on trial - The Carroll Case *Austr Soc Forensic Dentistry* 2001; 18: 6-8  
(Case-study, legal needs BMA)

## 2002

Bowers, C. M., Johansen, R. J. (2002) Photographic Evidence Protocol: The use of Digital Imaging Methods to Rectify Angular Distortion and Create Life Size Reproductions of Bite Mark Evidence *Journal Forensic Sciences* 2002; 47(1, Jan.) 178-185  
(Description, instrument (Digital Imaging methods) for correcting characteristic (inappropriate angle) of instrument (photography) for preserving/representing characteristics of skinmark and teeth/biting-mechanism)

Munang, L. A., Leonard, P.A., Mok, J. Y. Q. (2002) Lack of agreement on Colour Description between Clinicians Determining Childhood Bruising *J Clin Forens Med* 2002; 9(4):171-174  
 (Experiment, characteristic (reliability/agreement) of instrument (expert) for observing characteristic (colour) of skinmark for diagnosing age of bruise)

Surez-Penaranda, J. M., Rodriguez-Calvo, M. S., Ortiz-Rey, J. A., Munoz, J. I., Snchez-Pintos, P., Da Silva, E. A., De la Fuente-Buceta, A., Concheiro-Carro, L. (2002) Demonstration of Apoptosis in Human Skin Injuries as Indicator of Vital Reaction *International Journal of Legal Medicine* 2002; 116(2) April: 109-112  
 (Experiment, characteristic (apoptosis) of skinmark for diagnosing age of skinmark, not related to bma)

Delattre, V. Reynolds, R., Santos, A., Stimson, P. (2002) Teamwork in Action - Integration of the Forensic Sciences during Bitemark Investigations *Proceedings of the American Academy of the Forensic Sciences Annual Meeting*, Atlanta 2002  
 (Descriptive, legal/investigative needs from BMA)

Bisset, R. A., Thomas, N. B., Turnbull, I. W., Lee, S. (2002) Postmortem examination using Magnetic Resonance Imaging: Four Year Review of a Working Service *BMJ* 2002; 324: 1423-1424  
 (Review of instrument (MRI) for observing characteristics (various) for various post-mortem diagnoses )

Pretty, I.A., Hall, R. C. (2002) Forensic Dentistry and Human Bite Mark Issues for Doctors *Hosp Med* 2002; 63(8): 476-482  
 (Descriptive, introductory/manual, FO/BMA-general for health-personnel, comments on reliability)

Vogeley, E., Pierce, M. C., Bertocci, G. (2002) Experience with Woodlamp Illumination and Digital Photography in the Documentation of Bruises on Human Skin *Arch Pediatr Adolesc Med* 2002; 156(March) 265-268  
 (Descriptive, instrument (woodlamp illumination) for observing characteristics (various) for diagnosing skinmarks for various health-purposes, not related to bma)

Lee, L. Y., Ilan, J., Mulvey, T. (2002) Human Biting of Children and Oral Manifestations of Child Abuse: A Case Report and literature review *J Dent Child* 2002; 69(1): 92-95  
 (review of bma-literature, casestudy)

Fischman, S. L. (2002) Bite Marks *Alpha Omegan* 2002; 95(4 Dec.): 42-46  
 (Descriptive, introductory/manual, bma)

Kanable, R. (2002) Forensic Dentist is In: Investigators Can Learn the Truth from a *Tooth Law Enforcement Technology* 2002; 29(10): 80, 82, 84, 86-87  
 (Descriptive, introductory/manual, bma for investigators)

Webb, D. A., Sweet, D., Hinman, D. L., Pretty, I. A. Forensic implications of Biting Behaviour: A Conceptually Underdeveloped Area of investigation *J Forensic Sci* 2002; 47(1): 103-106  
 (Descriptive, motive/intention for biting behaviour)

Goldman, R. J., Salcido, R. (2002) More than One Way To Measure a Wound: An Overview of Tools and Techniques *Adv. Skin Wound Care* 2002; 15(5): 236-243  
 (Descriptive, characteristics (several) of skinmarks for different health purposes, not related to bma)

Saks, M.J. (ed) (2002) *Modern Scientific Evidence* 2002 West Publishing Co. New York  
 (Descriptive/Normative, characteristics of modern standards for general scientific inference, not related to bma)

Bowers, C. M., Johansen, R. J. Bitemark Evidence in Saks, M.J. (ed) (2002) *Modern Scientific Evidence* 2002  
 (Descriptive/normative, characteristics of modern standards for forensic scientific inference, related to bma)

Saks, M. J., Risinger, D. M., Thompson, W. C., Rosenthal, R. (2002) The Daubert/Kumho Implications of observer Effects in Forensic Science: Hidden Problems of Expectations and Suggestion *California Law Review* 2002; 90(1, Jan) 1-56  
 (Descriptive/normative, characteristics of modern standards for forensic scientific inference, related to bma)

## 2003

Acharya, A. B., Taylor, J. A. (2003) Are a Minimum Number of Concordant Matches Needed to Establish Identity in Forensic Odontology? *J Forensic Odontostomatology* 2003; 21: 6-13  
 (Descriptive/normative characteristics of modern standards for forensic inference about individual, related to bma)

Bariciak, E. D., Ploint, A. C., Gaboury, I., et.al. (2003) Dating of Bruising in Children: An Assessmemnt of Physician Accuracy *Pediatrics* 2003; 112: 804-807  
 (Experiment, characteristic (reliability) of instrument (expert) for observing characteristic (unspecified) of bruising for diagnosing age of bruising (in children) for healt purposes, not related to bma)

Kaur, S., Chattopadhyay, P. K. (2003) Sexual Dimorphism of Incisors: A Study of the Jat Sikhs *Legal Medicine* 2002; 5: S261-S62  
 (Experiment, prevalence of characteristic (morphological) of teeth/-biting-mechanism (incisors) for diagnosing sex of remains for identity-purposes, not related to bma)

Pretty, I. A. (2003) A Web-Based Survey of Odontologist's Opinions Concerning Bitemark Analysis *J Forensic Sciences* 2003; 48(5, Sept): 1-4  
 (Experiment, prevalence of characteristics (various beliefs about bma) of instrument (expert))

Kittleson, J. M., Kieser, J. A., Buckingham, D. M., Herbison, G. P. (2003) Weighing Evidence: Qualitative Measures of the Importance of Bitemark Evidence *J Forens Odontostomatology* 2003: (in press)

(Descriptive/normative, instrument (likelihood-approach) for observing characteristic (relative justification) of characteristics (various) of bitemarks and biting-mechanisms)

McNamee, A. H., Sweet, D. (2003) Adherence of Forensic Odontologist to the ABFO Guidelines for Victim Evidence Collection *J Forensic Sci.* 2003; 48(2): 382-385  
(Experiment, prevalence of characteristic (adherence to ABFO-guidelines for observing characteristics of bitemarks) of instrument (experts))

Ainslie, G. M., Reilly, J. (2003) The Use of Linear Scales in the photography of Skin Lesions *J Audiovisual Media med.* 2003; 26: 15-22  
(Descriptive, instrument (photography with linear scale) for preserving/representing characteristics (various) of skinmarks for forensic purposes, not bma-related)

Thali, M. J., Yen, K., Schweitzer, W., Vock, P., Boesch, C., Ozdoba, C., Schroth, G., Ith, M., Sonnenschein, T., Doernhofer, E., Scheurer, E., Plattner, T., Dirnhofer, R. (2003) Virtopsy a New Imaging Horizon in Forensic Pathology: Virtual Autopsy by Postmortem Multislice Computed Tomography (MSCT) and Magnetic Resonance Imaging (MRI) a Feasibility Study *J Forensic Sci.* 2003; 48(2): 386-403  
(Descriptive, instrument (Virtopsy by CT and MRI) for observing characteristics (various) of objects (various) for forensic purpose (general), not related to bma)

Thali, M.J., Braun, M., Markwalder, Th.H., Brueschweiler, W., Zollinger, U., Malik, N.J. Yen, K., Dirnhofer (2003) Bite Mark Documentation and Analysis: The Forensic 3D/CAD Supported Photogrammetry Approach *Forensic Science International* 2003; 135: 115-121  
(Descriptive, instrument (3D/CAD supported photogrammetry) for observing characteristics (various) of bitemarks and teeth/biting-mechanisms, for bma-purpose)

Brueschweiler, W., Braun, M., Dirnhofer, R., Thali, M. J. (2003) Analysis of Patterned Injuries and Injury-causing Instruments with Forensic 3D/CAD Supported Photogrammetry (FPHG): An Instruction manual for the Documentation Process *Forensic Sci. Int.* 2003; 132: 130-138  
(Descriptive, instrument (3D/CAD supported photogrammetry) for observing characteristics (various) of objects (various), for forensic purpose (general), not related to bma)

Thali, M.J., Braun, M., Wirth, J., Vock, P., Dirnhofer, R. (2003) 3D Surface and Body Documentation in Forensic Medicine: 3D/CAD Photogrammetry merged with 3D Radiological Scanning *J Forensic Sci.* 2003; 48(6): 1356-1365  
(Descriptive, instrument (3D/CAD supported photogrammetry) for observing characteristics (various) of bitemarks and teeth/biting-mechanisms, for bma-purpose)

Thali, M., Braun, M., Dirnhofer, R. (2003) Optical 3D Surface Digitizing in Forensic Medicine: 3D Documentation of Skin and Bone Injuries *Forensic Science International* 2003; 137: 203-208

(Descriptive, instrument (3D/CAD supported photogrammetry) for observing characteristics (various) of skin and bone, for forensic purpose (general), not related to bma)

Thali, M. J., Braun, M., Brueschweiler, W., Dirnhofer, R. (2003) Morphological Imprint: Determination of the Injury-causing Weapon from the Wound Morphology Using Forensic 3D/CAD Photogrammetry (FPHG) *Forensic Sci Int* 2003; 132(3): 177-181

(Descriptive, instrument (3D/CAD supported photogrammetry) for observing characteristics (various) of skin and bone, for diagnosing object of impact (not bma-related))

Bernitz, H., van Niekerk, P. J. (2003) Bungled Bite Mark Evidence Collection: A Proposed Protocol for the Prevention thereof *SADJ*. 2003; 58(1, Febr): 16-9

(Description/normative, instrument (procedure specifying kind of information/objects to be collected) for characteristic (predictive relevance) of instrument (expert) for observation of characteristics (various) of bitemarks and biting-mechanisms for bma-purpose)

Sperber, N. (2003) Investigation of Human Bite Marks, in Peterson, M.S., Durfee, M. (eds.) (2003) *Child Abuse and Neglect: Guidelines for Identification, Assessment, and Case Management*, 2003, 61-64

(Descriptive, introduction/manual, BMA-procedure for legal personnel?)

Ashton, W. (2003) An Unusual Bite-Mark Comparison *Identification Canada* 2003; 26(4): 20-23

(Descriptive, case-study)

Bowers, C.M., Johansen, R.J. (2003) *Digital Analysis of Bitemark Evidence Using Adobe Photoshop* Forensic Imaging Services, Santa Barbara, CA, 2003

(Descriptive, instrument (Digital analysis via Photoshop) for observing characteristics (various) of bitemarks and biting-mechanisms for bma-purposes)

Giannelli, P. C. (2003) Admissibility of Scientific Evidence *Oklahoma City UL Rev* 2003

(Descriptive, legal needs (reliability), forensic general, not related to bma)

## 2004

British Association for Forensic Odontology (2004) *Guidelines for Good Practice in Bite Mark Investigation and Analysis* BAFO, 2004

(Descriptive/normative, instrument (ASFO-guidelines) for characteristic (standardised information-collection) of instrument (expert) for observing characteristics (various) of bitemarks and teeth/biting-mechanisms for different bma-purposes)

Bernitz, H. (2004) *A Model to Determine the Individual Discrimination Potential of Numerically Analysed Dental Features in the Anterior Twelve teeth* (PhD-thesis) University of Pretoria, Pretoria, South Africa, 2004

(Experiment, characteristics (discriminating power) of characteristics (unknown) of biting-mechanisms (casts or natural?) for general bma-purposes general)

Dawes-Higgs, E. K., Swain, M.V., Higgs, R. J. E. D., Appleyard, R. C., Kossard, S. (2004) Accuracy and Reliability of a dynamic Biomechanical Skin Measurement Probe for the Analysis of Stiffness and Viscoelasticity *Physiological Measurement* 2004; 25: 97-105  
 (Experiment, characteristic (reliability) of instrument (skinprobe) for observing characteristics (stiffness and viscoelasticity) of human skin for purpose (unspecified) , not related to bma)

Sitiene, R. Zakarasm A., Pauliukkevicius, A., Kisielius, G. (2004) Morphologic, Experimental-Comparative Investigation as an Identification of the Injuring Instrument Method *Forensic Science International* 2004; 146: S59-S60  
 (Experiment, instrument (simulation technique) for diagnosing class of causal object of impact, not related to bma)

Sitiene, R., Varnaite, J., Zakaras, A. (2004) Complex Investigation of Body and Clothing Injuries During the Identification of the Assault Instrument *Forensic Science International* 2004; 146S: S59-S60  
 (Experiment, instrument (simulation-technique) for diagnosing class of causal object of impact, not related to bma)

Hughes, V. K., Ellis, P. S., Langlaois, N. E. (2003) The Perception of Yellow in Bruises *J Clin Forensic Med* 2004; 11: 257-259  
 (Experiment, characteristic (reliability) of instrument (non-experts and experts) for observing characteristic (colour (yellow)) of skinmark (on photography) for general forensic purpose, not related to bma)

Kouble, R.F., Craig, G.T. (2004) A Comparison Between Direct and Indirect Methods Available for Human Bite Mark Analysis *J Forensic Sci* 2004; 49(1, Jan): 1-8  
 (Experiment, characteristic (reliability) of instrument (experts and photocopier-produced overlays vs other methods for producing overlays) for observing characteristics (cutting edge profile) of biting-mechanisms (casts) and bitemarks (in pigskin) for diagnosing individual biting-mechanism)

Kaminski, J. A. (2004) Old Dogs Can Learn New Tricks - A New Application of the ABFO #2 Scale *J Forensic Sci* 2004; 49(6, Nov): 1332-1334  
 (Descriptive, instrument (ABFO #2 scale) for preserving/representing characteristics (unspecified) of bitemarks and biting-mechanisms for general bma-purposes)

James, H., Cirillo, G. N. (2004) Bite Mark or Bottle Top? *J Forensic Sci* 2004; 49(1): 1-3  
 (Case-study, false bitemark-positive)

Randerson, J. (2004) Bite-mark Evidence Can Leave a False Impression *New Scientist* 2004; 2438 (13th March):6  
 (Descriptive, legal needs, reliability of bma)

King, B. R. (2004) Cutaneous Injuries in Child Abuse Difficult and Controversial *Emergency medicine news* 2004; 26(6, June): 1-2  
 (Descriptive, legal needs, reliability of skinmark-diagnosis)

Whittaker, D.K. (2004) Bite Marks - the Criminal's Calling Cards *British Dental Journal* 2004; 196(6, Febr): 237  
 (Descriptive, legal needs, reliability of bma)

Gould, G. A. Forensic odontology: A Global Activity *CDA Journal* 2004; 32(5, May): 410-415  
 (Descriptive, introductory/manual, forensic odontology general)

Avon, S. L. (2004) Forensic odontology: The Roles and Responsibilities of the Dentist *J Canadian Dental Association* 2004; 70(7, Jul/Aug): 453-458  
 (Descriptive, introductory/manual, forensic odontology -general)

Spencer, D. E. Child Abuse: Dentists' Recognition and Involvement *CDA. Journal* 2004;32(4, April): 299-303  
 (Descriptive, introductory/manual, forensic odontology general)

Bowers, C. M. *Forensic Dental Evidence. An Investigators Handbook* 2004  
 (Descriptive, introductory/manual, forensic odontology general)

## 2005

Cambell, H. R. (2005) Review of Bitemark Evidence *J Forensic Sci.* 2005; 50(4):1  
 (Review of book)

Avon, S. L., Wood, R. E. (2005) Porcine Skin as an in vivo Model for Ageing of Human Bite Marks *J. Forensic Odontostomatology* 2005; 23(2, Dec.): 30-39  
 (Experiment, characteristics (unknown) of bitemarks (in live porcine skin) for diagnosing age of bitemarks)

Gorea, R. K., Jha, M., Jasuja, O. P., Vasudeva, K., Aggarwal, A. D. (2005) Marvelous Tools of identification - Bite Marks *Medico-Legal Update* 2005; 5(2)  
 (Experiment, characteristics (reliability) of instrument (human not further specified) for observing characteristic (similarity/difference) of characteristics (unspecified) of bitemarks (in natural human skin, foodstuffs, hobby clay) and biting-mechanisms (unknown if natural or cast)

Brown, R.S. (2005) Evidence-based Dentistry *Dent Today* 2005; 24: 14-16  
 (Descriptive/normative, instrument (evidence-based procedure) for dentistry, general)

Kieser, J.A. (2005) Weighing Bitemark Evidence A Postmodern perspective Forensic Science, Medicine, and Pathology 2005; 1(2, Jun)  
 (Descriptive/normative, instrument (epistemological and methodological norms) for observing characteristics (unknown) of bitemarks and biting-mechanisms)

McNamee, A. H., Sweet, D., Pretty, I. A. (2005) A Comparative Reliability Analysis of Computer-Generated Bitemark Overlays *J Forensic Science* 2005; 50(2): 401-406  
 (Experiment, characteristic (reliability) of instrument (expert and computer-generated overlays) for observing characteristics (position, area) of biting-mechanism (casts) for diagnosing causal individual biting-mechanism)

Martin-de las Heras, S., Valenzuela, A., Ogayar, C., Valverde, A.J., Torres, J.C. (2005) Computer-Based Production of Overlays from 3D-Scanned Dental Casts for Bite Mark Analysis *J Forensic Sci* 2005; 50(1, Jan): 1-7  
(Experiment, characteristic (reliability) of instrument (expert and DentalPrint software) for observing characteristics (position, area) of biting-mechanism (casts) for diagnosing state of position/area of biting-mechanisms (casts))

Thali, M.J., Braun, M., Buck, U., Aghayev, E., Jackowsky, C., Vock, P., Sonneschein, M., Dirnhofer, R. (2005) VIRTopsy- Scientific Documentation, Reconstruction and Animation in Forensic: Individual and Real 3D Data Based Geo-Metric Approach Including Optical Body/Object Surface and Radiological CT/MRI Scanning *J Forensic Sci* 2005; 50(2): 1-15  
(Descriptive, instrument (virtopsy), forensic general, not related to bma)

Freeman, A.J., Senn, D.R., Arendt, D.M. (2005) Seven Hundred Seventy Eight Bite marks: Analysis by Anatomical Location, Victim and Biter Demographics, Type of Crime, and Legal Disposition *J Forensic Sci* 2005; 50(6): 1-8  
(Epidemiological, prevalence of bitemarks in population (unknown) by body-part, victim/biter-demographics, crime and legal disposition (biter found guilty/innocent in case?))

Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005 (Book on BMA)

Vale, G.L. (2005) History of Bitemark Evidence, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 1-31  
(History of BMA)

McDowell, J.D. (2005) Role of Health Professionals in Diagnosing Patterned Injuries from Birth to Death, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 31-42  
(Descriptive, characteristics (various) of bitemarks and biting-mechanisms for diagnosing class and individual biting-mechanism)

Davis, J.H. (2005) Role of the medical Examiner/Coroner/Pathologist, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005  
(Descriptive, legal needs)

Delattre, V.F. (2005) Teamwork in Bitemark Investigation in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 53-59  
(Descriptive, investigative needs)

Bernstein, M.L. Nature of Bitemarks, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Deckers 2005: 59-81  
(Descriptive, characteristics (various, ad hoc) of skinmarks)

Bernstein, M.L. Reconstructive Bitemark Analysis, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 81-87  
(Descriptive/normative, instruments (general bma-procedure))

Golden, G.S., Wright, F.D. Photography, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 87-169  
(Descriptive, instrument (photo) for BMA)

Dorion, R.B.J. (2005) Digital Imagery, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 169-183  
(Descriptive, instrument (Digital Imagery) for BMA)

Sweet, D. (2005) Bitemarks as Biological Evidence, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 183-203  
(Descriptive, instruments (objects) for forensic diagnosis general))

Dorion, R.B.J. (2005) Bitemark Impressions, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 203-209  
(Descriptive, instruments/materials for preserving/representing skinmarks and biting-samples)

David, T.J. (2005) Scanning Electron Microscopy, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 209-217  
(Descriptive, instrument (Scanning electron microscope) for observing characteristics of skinmarks, bma-related)

Dorion, R.B.J. (2005) Nonperishables and Perishables, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 217-225  
(Descriptive, instruments (various objects) for diagnosing class and individual cause)

Dorion, R.B.J. (2005) Tissue Specimens, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 225-257  
(Descriptive, instrument for preserving/representing bitemarks)

Davis, J.H. (2005) Histology and Timing of injury, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 257-275  
(Descriptive, characteristics (histological) of skinmarks for diagnosing age of skinmarks)

Dorion, R.B.J. (2005) Human Bitemarks, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 323-389  
(Descriptive, characteristics (various, ad hoc) for diagnosing human or animal biting-mechanism)

Dorion, R.B.J., Souviron, R.R. (2005) Patterns, Lesions, and Trauma-mimicking Bitemarks, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 323-389  
(Descriptive, characteristics (various, ad hoc) of skinmarks for diagnosing cause being teeth or other object)

Johnson, T.L. (2005) The Suspect, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 415-423  
 (Descriptive, characteristics (various, ad hoc) of biting-mechanisms for diagnosing individual cause of bitemark)

Dailey, J.C. (2005) The Comparison, in Dorion, R. (2005) *Bitemark Evidence* New York: Marcel Decker 2005: 423-453  
 (Descriptive/normative, instrument (criteria) for observing characteristic (sufficient number of sufficiently relevant characteristics) of characteristics (various) of skinmarks and biting-mechanisms for diagnosing individual causal biting-mechanism)

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## Appendix 4 Denotation

### Denotation of propositions relevant to the Torgersen-case:

*PC: The suspect Torgersen is the causal agent of the victim's lethal/rape injuries which occurred between 11.00 and 11.30 in Skipergata 6b, Oslo?*

*BM: Torgersen is the causal agent of the bitemark observed on the left breast of the victim which occurred between 11.00 and 11.30 in Skipergata 6b, Oslo?*

*BM1: Torgersen's teeth/biting-mechanism is the causal object of the bitemark?*

*BM1.1: Torgersen's teeth/biting mechanism's state on bitemark-index1 is to a sufficient degree compatible with the bitemark's state on bitemark-index2?*

*BM1.11: T's teeth's state on bitemark-index1 is bmi1?*

*BM1.12: The bitemark's state on bitemark-index2 is bmi2?*

*BM2: The bitemark occurred simultaneously with the lethal and the rape injuries?*

*BM2.1: The bitemark's state on the time-index is equal to the lethal/rape injuries' state on the time-index?*

*BM2.11: The lethal/rape injuries' state on the time index is t1?*

*BM2.12: The bitemark's state on the time-index is t1?*

### Denotation of propositions generally relevant to bitemark-means:

*PC: The suspect ( $S = s$ ) is the causal agent of the victim ( $V = v$ )'s legal injuries ( $LI = li$ ) which occurred at time ( $T = t$ ) at place ( $PL = pl$ );*

*BM: s is the causal agent of the bitemark (crimemark ( $CM = cm$ )) which occurred at time ( $t$ ) at place ( $pl$ );*

*BM1: s' teeth/biting-mechanism (suspected mechanism ( $SM = sm$ )) is the causal object of the cm?*

*BM1.1: sm's state on bitemark-index1 ( $BMI1 = bmi1_{sm}$ ) is to a sufficient degree compatible with the  $CM = cm$ 's state on bitemark-index2 ( $BMI2 = bmi2$ )?*

*BM1.11:  $BMI1 = bmi1_{sm}$ ?*

*BM1.12:  $BMI2 = bmi2_{cm}$ ?*

*BM2: The  $CM = cm$  occurred simultaneously with the lethal and the rape injuries ( $LI = li$ )?*

*BM2.1:  $CM = cm$ 's state on the time-index ( $TI = t_{cm}$ ) is equal to  $LI = li$  state on the time-index ( $TI = t_{li}$ )?*

*BM2.11:  $TI = t_{li}$ ?*

*BM2.12:  $TI = t_{cm}$ ?*

**Denotation of persons, injuries, and other objects generally relevant to bitemark-means:**

*S = s: A particular individual suspected of being the causal agent of a particular legal injury.*

*V = v: A particular individual being the victim of the particular legal injury.*

*LI = li: A particular legally relevant injury.*

*T = t: A particular time interval determined for the legally relevant injury.*

*PL = pl: A particular place determined for the legally relevant injury.*

*CM = cm: A particular observable item (in our case, a bitemark) suspected of being an effect of the global causal mechanism which produced the particular legal injury.*

$SM = sm$ : A particular observable item (in our case, a teeth/biting-mechanism) suspected of being the object which directly caused the bitemark ( $cm$ ).

$BMI1$ : The index of characteristics used to classify teeth/biting-mechanisms ( $sms$ ) in given bitemark-situations.

$BMI1 = bmi1_{sm}$ : The particular  $BMI1$ -configuration or -profile observed of a particular teeth/biting-mechanism ( $sm$ ).

$BMI2$ : The index of characteristics used to classify bitemarks ( $cms$ ) in given bitemark situations.

$BMI2 = bmi2_{sm}$ : The particular  $BMI2$ -configuration or -profile observed of a particular bitemark on human skin ( $cm$ ).

$TI$ : The index of characteristics used to determine the time of occurrence of skin injuries.

$TI = tli$ : The particular  $TI$ -configuration or -profile observed of a particular legally relevant injury ( $li$ ).

$TI = tli_{cm}$ : The particular  $TI$ -configuration or -profile observed of a particular bitemark ( $cm$ ).