Pre-hospital trauma interventions

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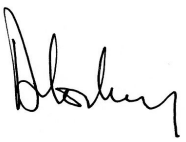
I, David Lockey confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.



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Abstract

Considerable variation exists in the type and quality of interventions carried out on victims of major trauma in the pre-hospital phase of care. One model of care consists of high level interventions delivered by a doctor-led team. Examining two controversial areas of treatment (traumatic cardiac arrest and advanced airway management), this thesis set out to determine the quality and potential shortfalls of current practice and how they might be improved.

A systematic review of traumatic cardiac arrest survival confirmed that outcome was historically very poor. A study of the largest series of traumatic cardiac arrest reported to date then suggested that a doctor –led system was associated with survival rates which were greater, and which were compatible with those after medical cardiac arrest. A significant proportion of survivors were victims of penetrating trauma who had been treated with on-scene thoracotomy. I thus examined the use, success rate and place of this intervention through analysis of the only reported case series. Finally, I considered how new or established interventions might be best applied in the early phase of trauma care to improve outcome, proposing a treatment algorithm to guide current management.

Advanced airway management is presented as a controversial subject with uncertainty about who should deliver it and how it should be performed. The data presented demonstrates that, in a UK system ambulance service, interventions fail to deliver adequate airway care to trauma victims. In terms of doctor-delivered care, a meta-analysis is presented which demonstrates that doctors have better intubation success rates than paramedics, even when drug assistance and high levels of training are provided. The largest series of physician-delivered intubation then confirms this position. Lastly, a pre-hospital airway consensus process is described which attempts to improve the quality of data to guide future service development and research.

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Glossary of Abbreviations

ACS – American College of Surgeons

ASCOT – American college of surgeons committee on trauma

EMS - Emergency medical services

$ETCO_2$ - End tidal carbon dioxide

ETI – Emergency Tracheal Intubation

IQR - Inter-quartile range

LAA – London's Air Ambulance

NAEMSP – National Association of EMS Physicians

REBOA – Resuscitative Endovascular Balloon Occlusion of the Aorta

RCT - Randomised controlled trial

R&D – Research and Development

RSI - Rapid sequence induction

SOP – Standard Operating Procedure

TCA – Traumatic Cardiac Arrest

TI - Tracheal intubation

Published papers related to this thesis:

Traumatic Cardiac Arrest

1: Lockey DJ, Weaver AE, Davies GE. Practical translation of hemorrhage control techniques to the civilian trauma scene. Transfusion. 2013 Jan;53 Suppl 1:17S-22S.

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2: Lockey DJ, Lyon RM, Davies GE. Development of a simple algorithm to guide the effective management of traumatic cardiac arrest. Resuscitation. 2013 Jun; 84(6):738-42.

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3: Davies GE, Lockey DJ. Thirteen survivors of prehospital thoracotomy for penetrating trauma: a prehospital physician-performed resuscitation procedure that can yield good results. J Trauma. 2011 May;70(5):E75-8.

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4: Soar J, Perkins GD, Abbas G, Alfonzo A, Barelli A, Bierens JJ, Brugger H, Deakin CD, Dunning J, Georgiou M, Handley AJ, Lockey DJ, Paal P, Sandroni C, Thies KC, Zideman DA, Nolan JP. European Resuscitation Council Guidelines for Resuscitation 2010 Section 8. Cardiac arrest in special circumstances: Electrolyte abnormalities, poisoning, drowning, accidental hypothermia, hyperthermia, asthma, anaphylaxis, cardiac surgery, trauma, pregnancy, electrocution. Resuscitation. 2010 Oct;81(10):1400-33.

Author contribution: This is a large section of international guidelines with multiple topics. I wrote and submitted only one sub-section to this to this section (Traumatic Cardiac Arrest). First author (section editor) read and suggested minor changes before submission.

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11. Fevang E, Lockey D, Thompson J, Lossius HM; Torpo Research Collaboration. The top five research priorities in physician-provided pre-hospital critical care: a consensus report from a European research collaboration. Scand J Trauma Resusc Emerg Med. 2011 Oct 13;19:57

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Author Contribution: I conceived this commentary with the first author. I supervised the first author in writing and submitting the manuscript.

15. Manuscripts not yet published:

- A prospective study examining the frequency of on scene airway compromise in major trauma patients and the success rates of airway management by paramedics and doctor-paramedic teams. Lockey DJ, Healey B, Chalk G and Davies GE.
- Intubation success rates and the management of failed intubation in a physician-led pre-hospital trauma service. Lockey DJ, Crewdson K, Weaver A & Davies GE.

Section I: Pre-hospital Trauma Care

Chapter 1.1: The challenges of pre-hospital trauma care in the UK

1.1.1 BACKGROUND

One of the advantages of writing this thesis relatively late in my career is that I have been privileged to work in and observe a number of civilian and military trauma services. I have seen transformation in both areas. When I qualified in 1988 trauma care was inconsistent and the Advanced Trauma Life Support course (1) was being introduced into UK practice in an attempt to standardise basic trauma practice. Now after more than twenty years and the publication of a series of reports recommending the proper organisation of trauma services, long awaited trauma networks are operational. In military practice the survival and clinical governance process surrounding the treatment of severely injured patients has changed between my first and last overseas deployments, now yielding exceptional survival rates. Despite such progress, considerable variation in care quality and outcome still exists. Between 2003 and 2008, I edited a series of articles in the journal *Resuscitation* that detailed the operation of emergency medical service (EMS) systems in around thirty different countries. In quality terms a 'postcode lottery' exists on a large scale even in countries with similar income and infrastructure (2). The international development of EMS and trauma care has produced almost every variation possible. Some countries have put significant effort and resource into advanced pre-hospital services and others are still rudimentary even in 2013.

In trauma care generally, there have been major steps forward in system development in the UK. Until the launch of trauma networks in April 2012 only around 50% of eligible hospitals provided data for the national Trauma Audit and Research Network (TARN) (3). Most regions had little idea and no easy

means of determining what was really going on with trauma care in their catchment population. A key move forward is that UK trauma networks have been encouraged to take responsibility for injured patients from point of injury to rehabilitation (4). We are a long way from consistent high level trauma care through to rehabilitation but there are promising signs and performance is at least now being measured.

Development of pre-hospital trauma care has been less consistent. In 1997 one of the editors of the Annals of Emergency Medicine noted that, despite the huge worldwide expenditure on pre-hospital services, the evidence base for the entire subject was less than that of constipation or urticaria (5). Not a great deal has changed. Almost the entire evidence base for pre-hospital medical care comes from variable quality retrospective database studies. Only a handful of randomised controlled studies have been performed and the barriers to the conduct of studies in unconsented critically unwell patients have been formidable (6). The most recent attempt to perform a large randomised controlled study in pre-hospital care was the Head Injury Retrieval Trial (HIRT) in Sydney, Australia (7). The study was designed to measure neurological outcome in head injured patients who were randomised to treatment by a physician-paramedic aeromedical team or standard ambulance service care. Despite gaining ethical approval and funding (over 20 million Australian Dollars) the study was eventually terminated before achieving the required number of subjects. The problems of interagency conflict resulted in the ambulance service dispatching a physician response to patients randomised to standard care. This, along with poor recruitment, led to considerable crossover in the two arms of the study. The results were inconclusive even when a treatment

received (rather than intention to treat) analysis was carried out. In sub-group analysis, physician delivered care did appear to be beneficial in transportation accidents. This study clearly demonstrates some of the difficulties of carrying out high quality research in the pre-hospital environment.

I have spent the last 15 years working in a pre-hospital trauma service operating with a physician–paramedic model. The service was developed against considerable resistance by a number of individuals who believed that some severely injured patients require urgent treatment that cannot wait until arrival in the emergency department. Similarly, some felt that taking critical care interventions to the pre-hospital phase of care would provide treatment when the patient needs it, whilst others argued that many interventions can wait until arrival in hospital, and that short time to definitive intervention would reduce mortality. In the UK, physician-led helicopter services were particularly controversial (8) and had many detractors. Despite this, the use of the helicopter delivered physician-paramedic model has increased considerably in the UK over the last decade (9).

The last five years has seen the publication of several papers which have attempted to bring together the available evidence for the various components of on–scene advanced care. The benefits of Helicopter Emergency Medical Services (HEMS) (10), cost effectiveness of physician staffed air ambulances (11) and the influence of physician helicopter services on on-scene times (12,13) have been examined by a research group in the Netherlands in parallel with developments of HEMS services in that country. The influential George Institute for International Health in Australia performed a systematic review of the costs and benefits of HEMS services in 2010 (14), while the influence of

helicopter deployment on UK trauma mortality was examined by the then national clinical director for trauma care (15). A very large US study was also published (16) which examined mortality benefit to trauma patients transported by (mostly paramedic staffed) helicopters from scene. The results of these systematic reviews and studies have all suggested that trauma patients benefit from advanced care delivered to the scene. The papers from the Netherlands demonstrated that HEMS staffed by physicians contributed to between 1.1 and 12.1 additional survivors per 100 HEMS deployments, and the most comprehensive four studies identified at systematic review suggest that there are 2.7 additional survivors per 100 HEMS deployments (10). In addition in their own system they demonstrated 29 additional survivors in a four year period, and that the costs of HEMS assistance fell below the nationally accepted funding threshold for calculated quality adjusted life years (11). Authors from the George Institute in Australia also examined the cost effectiveness of HEMS services. Systematic review of the available literature indicated five studies where the increased expense associated with HEMS was not associated with demonstrated benefit and eight where cost effective benefit was demonstrated (14). In the UK, Butler et al performed a systematic literature review of helicopter transfer from scene and demonstrated a mortality benefit in trauma patients (15). A retrospective cohort study (16) examining the outcome of 223,000 patients from the US demonstrated that, after adjusting for multiple confounding factors (particularly injury severity), transport to trauma centres by helicopter delivered a 1.5% reduction in the absolute risk of death. All of the studies above made some comment about the difficulties of obtaining high quality data and of adjusting for confounding factors. It appears that provision of

high level pre-hospital care delivered by helicopter is beneficial to trauma patients but it is not clear if the benefit is due to the provider level, particular interventions, mode or speed of transport or care after arrival in hospital. Which patient groups benefit most, and whether the distance to definitive care influences outcome, is also unclear.

Pre- and in-hospital trauma care in the UK has been the subject of many adverse reports over the last twenty years (17). Internationally the UK has been seen to move to an 'Anglo-American' paramedic-led model of pre-hospital care in contrast to the 'Franco-German' physician-led model of care seen in many other European countries. In the UK, paramedics were first trained in the 1970's and the first national training course commenced in 1985. Paramedic training then became more uniform and they have provided the bulk of clinical pre-hospital care in the UK for many years. Their advanced skills have included advanced airway management – up to and including intubation without drugs and the administration of intravenous fluid and drugs. Unfortunately the benefit of nearly every extended skill used by paramedics in trauma has been questioned. The administration of intravenous fluid has been limited to the most severely hypovolaemic for many years (18), the value of tracheal intubation without drugs is questionable (19,20) and few drugs are indicated in the early phases of trauma (although tranexamic acid is now administered by some UK ambulance services) (21). It is perhaps unfair that effectiveness is usually judged on the basis of interventions rather than the more difficult to measure safe and effective scene management which may result from experience. What is clear is that most UK paramedics only rarely encounter major trauma (17) and enhanced care teams treat trauma patients more frequently. Doctors have

been active in UK pre-hospital care for many years but recent efforts to ensure that high-quality care is delivered have led to the UK becoming the first European country to recognise pre-hospital emergency medicine as a subspecialty.

Against this background, I perceived some of the key remaining 'big questions' in pre-hospital trauma care to be:

a. What *can* be achieved in the pre-hospital phase of care?
b. What *needs* to be done in the pre-hospital phase of care?

and

c. Who should deliver this care?

I recognised that tackling these questions in anything but relatively small clinical areas for the purpose of this thesis was unrealistic and therefore concentrated on two clinical areas of pre-hospital critical care: traumatic cardiac arrest and pre-hospital airway management. I selected these areas because they are encountered frequently in my own practice and are highly controversial. The treatment of traumatic cardiac arrest has been considered by many to be futile and pre-hospital airway management is probably the most contentious area of pre-hospital practice. The need for advanced airway management, the methods by which it should be achieved and who should do it have all been the subject of numerous studies.

That my choice of subject matter was sensible was supported by a consensus process in 2010 (22) which attempted to define the five priority research areas for physician pre-hospital care. Airway management was one of the five priority areas and traumatic cardiac arrest fits well into some of the other categories

particularly the staffing, training and value of physicians in pre-hospital trauma care and the time windows for critical interventions (Table 1.1).

Table 1.1:

The top five priority research areas in physician pre-hospital care (22)

Research Area	Key Research Questions
Appropriate staffing and training in pre-hospital critical care and the effect on outcomes: This includes the value of physicians in the pre-hospital field	What staffing and training is required to meet the needs of specific groups of critical care patients in the pre-hospital environment? Is the cost of high level staffing worthwhile? Which training methods are successful and how are the skills maintained and assessed?
Advanced airway management in pre-hospital care: What is best for the patient?	What are the indications for advanced airway interventions? What factors influence the decision to intubate and what is the physicians role in decision making? When should alternative airway devices or conservative airway manoeuvres be used?
Define time windows for key critical interventions that are indicated in the pre-hospital phase of care	How does time to definitive in-hospital care influence pre-hospital decisions and how do pre-hospital decisions influence time to definitive care? Do pre-hospital management protocols result in better adherence to evidence based guidelines in time critical conditions? Which clinical conditions are time limited or time dependent?
The role of pre-hospital ultrasound	Which ultrasound examinations can be reliably transferred to the pre-hospital setting? How does pre-hospital ultrasound affect patient management and the patient pathway? How should providers achieve and maintain specific ultrasound skills?
Dispatch / activation criteria for pre-hospital critical care services	Which criteria accurately identify high acuity patients who require critical care attendance or transport? Do established dispatch systems efficiently target high resource services? What defines under- and overtriage in specific patient groups and what rates do current systems produce?

Chapter 1.2 : Background to the emergency medical system in which the studies in this thesis were conducted.

1.2.1 UK EMS

The UK EMS system is activated by single number access to all emergency services. Ambulance services are organised on a regional basis and ambulance service providers are at paramedic or Emergency Medical Technician (EMT) level. Paramedic qualifications are uniform between ambulance services. In 2006 the majority of paramedics were direct (rather than degree) entry, and medical support for pre-hospital care was inconsistent. Longstanding voluntary general practitioner and hospital doctor support was provided through local schemes under the national charity BASICS (23). Hospital-based physician-staffed schemes have run in several centres with variable staffing levels and availability. The Royal College of Surgeons of Edinburgh has an established Faculty of Pre-hospital Care to develop the standard and consistency of pre-hospital medicine. The EMS system in London has developed differently than in some other areas of the UK and has had reasonably consistent physician–led care for many years.

1.2.2 LONDON'S AIR AMBULANCE (LAA)

In 2009, an expert consensus group which I co-chaired described a number of 'fixed system variables' to encourage uniform reporting of pre-hospital advanced airway data (24). The key information describing the system in which I work and in which the studies described in this thesis are based is detailed below.

London’s Air Ambulance was the first helicopter service in the UK to provide a consistent doctor-paramedic team to attend trauma incidents. It commenced operation in 1988 and is jointly funded between charitable and National Health Service resources. In the initial years of operation focus was only on provision of a daytime helicopter trauma service. This has evolved to include fast response car trauma services at night and a daytime physician response service that is tasked to medical emergencies (25). The service is based at a London teaching hospital major trauma centre, is tasked by the ambulance service, and provides a service to the population and hospitals in the Greater London area (7-10 million people in an area of approximately 5,000 square kilometres). Mutual aid is also provided to neighbouring ambulance services where requested (26).

A doctor – paramedic team is delivered by helicopter (in the daytime) and by fast response car at night. Flight paramedics work in the ambulance control room and use dispatch criteria to target patients with severe trauma. The doctor – paramedic team are always dispatched in addition to the standard land ambulance response. The service attends an average of 5-6 trauma patients per day. Doctors are experienced emergency physicians or anaesthetists with in-hospital anaesthetic experience and pre-hospital training. Flight paramedics have specific training to equip them as members of the pre-hospital team.

Section II: Traumatic Cardiac Arrest

Chapter 2.1: Traumatic Cardiac Arrest - Background

2.1.1 INTRODUCTION

The management of cardiac arrest has been the subject of clinical and research interest for many years (27). The European Resuscitation Council, American Heart Association and other key organisations collaborate through the International Liaison Committee on Resuscitation (ILCOR) to achieve consistency in management guidelines (published every 5 years) (28). Innovations in management have been subject to intense scrutiny before inclusion in such guidelines and this appears to have stimulated an improvement in the number and quality of clinical trials on the subject. These advances have primarily related to medical cardiac arrest, the most common cause of which is ischaemic heart disease.

The much less common scenario of cardiac arrest associated with trauma (TCA) has received less attention. Resuscitation in such circumstances has resource implications (29), presents risks to rescuers and, with few neurologically intact survivors reported, its appropriateness has been frequently questioned (30-32). However, the evidence base relating to TCA outcome is far from comprehensive. I thus performed a systematic literature search to establish the survival rate after TCA resuscitation.

2.1.2 METHODS

The guidelines for systematic reporting of randomised controlled trials described in the QUORUM guidelines (33) (and more recently the PRISMA statement (34)) were modified and used to develop a search strategy.

Medline, Embase and the Cochrane Central Register of Controlled Trials were searched using the following strategy:

(cardiac arrest [All fields] OR cardiopulmonary resuscitation [All fields]) AND (traum* [All field]) AND (mortality OR outcome OR survival (All fields])

Where these terms included:

1. cardiac arrest: "heart arrest"[MeSH Terms] OR ("heart"[All Fields] AND "arrest"[All Fields]) OR "heart arrest"[All Fields] OR ("cardiac"[All Fields] AND "arrest"[All Fields]) OR "cardiac arrest"[All Fields]
2. cardiopulmonary resuscitation: "cardiopulmonary resuscitation"[MeSH Terms] OR ("cardiopulmonary"[All Fields] AND "resuscitation"[All Fields]) OR "cardiopulmonary resuscitation"[All Fields]
3. mortality: "mortality"[Subheading] OR "mortality"[All Fields] OR "mortality"[MeSH Terms]
4. survival: "mortality"[Subheading] OR "mortality"[All Fields] OR "survival"[All Fields] OR "survival"[MeSH Terms]

The search was limited to articles published in English between 01/01/1960 and 31/08/2005. The end date relates to the time point before I commenced the first studies described in this thesis. The results informed the planning of these studies. The search was re-run on 31st January 2013 to check for new material and this is commented on in the discussion section of this chapter.

Abstracts were screened for relevance and, where appropriate, full text articles obtained. Full text articles were searched for additional material by examination of quoted references. The results of the search are shown in Figure 2.1 and the relevant studies identified are listed in Table 2.1 for adult and mixed studies and Table 2.2 for paediatric studies.

2.1.3 RESULTS

Figure 2.1 Survival in traumatic cardiac arrest: search results

Table 2.1 Traumatic cardiac arrest survival: adult and mixed studies

Study	Year	Study population	Patients (total)	Survivors (%)	Good neuro outcome	Blunt (No of Survivors)	Penetrating (No of survivors)
Harnar TJ (35)	1981	Trauma Centre thoracotomy	100	24 (24)	-	65(8)	35 (16)
Shimazu (36)	1983	TCA at hospital admission	267	7 (2.6)	4 (1.5)	-	-
Copass M (37)	1984	CPR out of hospital	131	30(23)		107(12)	24(18)
Aprahamian C (38)	1985	TCA out of hospital	95	3 (3.2)	-	-	-
Wright S (39)	1989	TCA on scene	47	0 (0)	0	58 (0)	9 (0)
Durham LA (40)	1992	CPR out of hospital	207	18(8.2)		27(0)	180(18)
Rosemurgy A (30)	1993	CPR out of hospital	138	0(0)	0	96(0)	42(0)
Fulton R (41)	1995	TCA out of hospital / ED	173	3(1.7)	-	-	-
Quintans-Rodriquez A (42)	1995	CPR out of hospital	11	2(18)	-	-	-
Falcone R (43)	1995	CPR on scene or in flight	320	6(1.9)	-	284(5)	36(1)
Lawhon J(44)	1995	CPR pre-hospital / ED	47	2(4.3)	-	47(2)	0(0)
Pasquale M (29)	1996	Pre-hospital CPR	106	3(2.8)		85(2)	21(1)
Margolin D (45)	1996	Pre-hospital CPR	67	13(19)	6	53(12)	14(1)
Cocanour C (46)	1997	Pre-hospital CPR	11	0	0	0(0)	11(0)
Kuisma M (47)	1997	Pre-hospital CPR	15	0	0	-	-
Stratton S (48)	1998	Pulseless at scene	879	9(1)	-	382(5)	497(4)
Battistella F (49)	1999	CPR pre-hospital or ED	604	16(2.6)	-	304(4)	300(2)
Coats T (50)	2001	Pre-hospital thoracotomy	39	4(10)	-	0(0)	39(4)
Martin S(31)	2002	Pre-hospital blunt trauma / PEA	110	1(0.9)	0	-	-
Cera S (51)	2003	CPR on admission	161	15(9.3)	-	-	-
Alanezi K (52)	2004	Pre-hospital CPR	35	0(0)	0	-	-
Stockinger Z (32)	2004	Pre-hospital CPR	588	22(3.7)	-	194(12)	341(3)
Fialka C (53)	2004	Open chest CPR in ED	38	4(10.5)	4		
Pickens J (54)	2005	Pre-hospital CPR	184	14(7.6)	-	-	-
Di Bartolomeo S (55)	2005	Pre-hospital CPR	29	2(6.8)	0	29(2)	0(0)
TOTALS	-	-	4402	198(4.49)	-	1731(64)	1549(68)

TCA – Traumatic Cardiac Arrest, CPR- Cardiopulmonary Resuscitation, ED – Emergency department, PEA – Pulseless electrical activity "-" Data not available

Table 2.2 Traumatic cardiac arrest survival: paediatric studies

Study	Cause of arrest	Patients	Survivors (%)
Calkins 2002 (56)	Trauma	25	2 (8.0)
Perron 2001 (57)	Trauma	729	165 (22.6)
Fisher 1999 (58)	Trauma	65	1 (1.5)
Li 1999 (59)	Trauma	957	225 (23.5)
Suominen 1998 (60)	Trauma	41	3 (7.3)
Hazinski 1994 (61)	Trauma	30	0 (0)
Engdahl 2003 (62)	All	98	5 (5.1)
Sirbaugh 1999 (63)	All	300	6 (2.0)
Schindler 1996 (64)	All	80	6 (7.5)
Hickey 1995 (65)	All	95	15 (15.8)
Mogayzel 1995 (66)	All	438	15 (3.4)
Kuisma 1995 (47)	All	79	5 (6.3)
Losek 1987 (67)	All	114	9 (7.9)
TOTALS	-	3051	457(14.9)

2.1.4 DISCUSSION

This literature review confirmed that the reported survival rates for traumatic cardiac arrest were very poor in 2005. In the relevant identified studies the pooled reported number of survivors was 198 out of 4402 (4.5%) for adults and 457 out of 3870 (14.9%) for children. The survival rates reported were very variable and ranged from 0 – 24% in adult studies and 0 – 23% in children. The survival rates by mechanism (where reported) for adults were 3.7% and 4.3% for penetrating and blunt trauma respectively (p= 0.9 by 2-sided Chi squared test). However, the pooling of data in this literature review has marked limitations. The relevant studies are very heterogeneous, with data collated with quite different objectives. For example some studies only included patients who met local criteria for emergency thoracotomy (35,50), and one only collected data relating to PEA arrest (31). In addition, some studies were broadly inclusive (and might therefore be expected to report lower survival rates), whilst others only included patients transported to hospital, or those in whom CPR was only initiated after they were received in hospital (thereby excluding patients where resuscitation was discontinued in the pre-hospital phase). Some studies also included patients unrepresentative of more 'standard' hypovolaemic trauma (e.g. hangings, drowning and burns), in whom prognosis might be expected to differ. The data also demonstrated surprising anomalies in the definition of cardiac arrest. Most studies only included patients who required cardiopulmonary resuscitation after cardiac arrest was established but some included patients who were 'peri arrest'. This may have significantly improved the chances of survival. Most of the published studies originate in the

USA but even within this one country there was significant variation in the provision of pre-hospital advanced interventions for trauma on a regional and historical basis. These variables may have influenced survival either negatively (increased time on scene, harmful interventions) or positively (useful interventions improving survival).

My review of out-of-hospital paediatric cardiac arrest demonstrated survival rates ranging from 0-22.6% [Table 2.2]. As with the adult data the case mix of the studies varies in terms of definition of cardiac arrest, but so too does the upper age limit of subjects. Many studies exclude patients in whom resuscitative efforts were terminated in the pre-hospital phase and those in whom resuscitation was not attempted at scene or after arrival in the emergency department. Where traumatic cardiac arrest was the primary focus of the study, patients with a hypoxic mechanism of injury (electrocution, drowning, burns / smoke inhalation) were used in the analysis of some studies but not others. There are only two large paediatric studies which exclusively address TCA (57,59), perhaps because paediatric TCA is relatively uncommon in most EMS systems. Such data are thus limited. The two studies conducted by Perron (2001) and Li (1999) documented relatively high survival rates- 22.6% and 23.5% respectively (57,59). Both studies used the National Paediatric Trauma Registry (NPTR) as their data source. These survival rates may be spuriously high because some patients described as ‘receiving CPR’ may have received only other pre-hospital interventions such as intravenous fluid therapy or inotropic drug support and not actually sustained cardiac arrest (68). One of the studies (59) acknowledged that children with respiratory but not cardiac arrest may have had CPR commenced on scene. Perron and co-workers also

included all patients aged less than 19 years. The main outcome measure for the study was survival to trauma centre discharge rather than hospital discharge (57). Li and co-workers excluded children pronounced dead on scene. If analysis is performed for only those patients who were pulseless at time of presentation to the emergency department, the survival rate decreases from 23.5% to 1.5% (59).

The timing of loss of vital signs is also important in the interpretation of other smaller published studies. One study reported no survivors among children presenting to an emergency department in cardiac arrest (61). An 8% survival rate was recorded in another study but the two survivors had vital signs in the pre-hospital setting and CPR was started in the emergency department (56). Hickey and co-workers reported a survival rate of 15.8%. Their study included children who received initial treatment in the emergency department as well as those who underwent resuscitation at other hospitals and were subsequently transferred to their centre. The authors acknowledge that, in general, only successfully resuscitated patients were transferred; 12.5% of patients who were pulseless on EMS arrival survived. Patients who died in the pre-hospital phase were excluded (65).

A comprehensive review was published in 2005 that documented a long term survival rate of 6.7% for children sustaining out-of-hospital cardiac arrest of any cause. The same study concluded that only 1.1% of trauma patients in cardiac arrest survived to hospital discharge. In this publication the term ‘trauma’ describes blunt or penetrating injury, child abuse, burns and smoke inhalation (68). Drowning is the most common cause of accidental death in children (69) and a survival rate of 22.7% was recorded for this patient subgroup (68).

A significant issue with both the adult and paediatric data is that, although survival is usually documented, the degree of neurological impairment is rarely reported. In the reviewed adult data, there were only 14 survivors with documented good neurological outcome out of 372 cardiac arrest patients. The remaining 184 survivors from 4030 cardiac arrest victims have no documentation of neurological status. All of the studies used retrospectively collected (and often incomplete) data extracted from trauma databases.

Whilst this review of the TCA literature revealed it to be inconsistent and heterogeneous, survival rates appear generally poor in all patient groups. There is low level, inconsistent published evidence that some patient sub groups may have higher survival rates if basic or advanced resuscitation interventions are carried out in a timely manner. These may include thoracotomy in penetrating trauma (35) and basic resuscitation of children in respiratory arrest (59).

On the basis that the treatment of traumatic cardiac arrest was considered by some key US clinicians to be usually futile and an inappropriate use of resources (30,32,49), and that highly functioning survivors appeared rare, the National Association of EMS Physicians (NAEMSP) and the American College of Surgeons Committee on Trauma (ACSCOT) produced and published guidelines in 2003 regarding the withholding or termination of resuscitation in pre-hospital traumatic cardiopulmonary arrest (70). These acknowledged that the evidence base relating to TCA was small, and substantially built on data relating to emergency thoracotomy. The reliance on literature where immediate thoracotomy is available may account for the fact that this guideline documents higher survival rates for penetrating trauma than for blunt trauma.

The guidelines supported withholding or termination of out-of-hospital resuscitation for adult traumatic cardiopulmonary arrest (TCPA) where patients met the specific criteria listed below (70):

1. Resuscitation efforts may be withheld in any blunt trauma patient who, based on out-of-hospital personnel's thorough primary patient assessment, is found apnoeic, pulseless, and without organized ECG activity on the arrival of EMS at the scene.

2. Victims of penetrating trauma found apnoeic and pulseless by EMS, based on their patient assessment, should be rapidly assessed for the presence of other signs of life, such as pupillary reflexes, spontaneous movement, or organized ECG activity. If any of these signs are present, the patient should have resuscitation performed and be transported to the nearest emergency department or trauma centre. If these signs of life are absent, resuscitation efforts may be withheld.

3. Resuscitation efforts should be withheld in victims of penetrating or blunt trauma with injuries obviously incompatible with life, such as decapitation or hemicorporectomy.

4. Resuscitation efforts should be withheld in victims of penetrating or blunt trauma with evidence of a significance time lapse since pulselessness, including dependent lividity, rigor mortis, and decomposition.

5. Cardiopulmonary arrest patients in whom the mechanism of injury does not correlate with clinical condition, suggesting a non-traumatic cause of the arrest, should have standard resuscitation initiated.

6. Termination of resuscitation efforts should be considered in trauma patients with EMS-witnessed cardiopulmonary arrest and 15 minutes of unsuccessful resuscitation and cardiopulmonary resuscitation (CPR).

7. Traumatic cardiopulmonary arrest patients with a transport time to an emergency department or trauma centre of more than 15 minutes after the arrest is identified may be considered non-salvageable, and termination of resuscitation should be considered.

8. Guidelines and protocols for TCPA patients who should be transported must be individualized for each EMS system. Consideration should be given to factors such as the average transport time within the system, the scope of practice of the various EMS providers within the system, and the definitive care capabilities (that is, trauma centres) within the system. Airway

management and intravenous (IV) line placement should be accomplished during transport when possible.

9. Special consideration must be given to victims of drowning and lightning strike and in situations where significant hypothermia may alter the prognosis.

The text of this guideline did contain comment that the recommendations presented were based on the available research to date and are subject to change based on advances in trauma care. Four of the studies identified in the literature review above which all have higher survival rates than the mean 4.5 % (51,53-55) were not published when these guidelines were published. It was also made clear that there are several groups of patients that are not considered by the recommendations including paediatric patients, patients in whom a medical cause may have precipitated the trauma event and patients with complicating factors, such as severe hypothermia.

In 2005 the evidence base for survival in traumatic cardiac arrest demonstrated poor overall survival. The evidence base was heterogeneous and difficult to interpret. Some studies did demonstrate relatively high survival rates in specific patient groups but the generalizability of these small studies to other populations was obscure. US guidelines provided clear recommendations on when EMS providers should consider termination or withholding resuscitation attempts.

The search strategy was repeated on January 31st 2013 to establish if there had been any major changes to the evidence base on this subject. There were eight relevant new studies. One was the study presented in the next chapter. Three were case reports involving one patient each. Of the remaining four studies (71-74) eleven survivors were reported out of 421 patients (2.6%). A study involving

89 survivors from Australia (71) reported two survivors from penetrating trauma and two from blunt trauma – one from electrical injury and one from hypoxaemia. A US study (72) reported the fact that termination of resuscitation guidelines were not being followed and commented that none of 43 TCA victims survived after transport to the emergency department. A larger study from France (73) reported 6 survivors out of 268 (2.2%) and noted that outcome was poor in TCA but not significantly different to out of hospital medical cardiac arrest attended by the same EMS. The addition of these data to those reported above has little impact, but some of the issues raised in the publications are relevant to the discussions in the remaining chapters of this section.

Our pre-hospital physician-led service serves a large population and frequently encounters traumatic cardiac arrest. We also deliver all currently available advanced resuscitation interventions to scene. On this basis I wished to test the hypothesis that the provision of advanced trauma resuscitation in the pre-hospital phase to patients in traumatic cardiac arrest is not futile and may result in neurologically intact survivors. I also wished to test the validity of the existing US guidelines by recording whether any survivors exist that would not have been resuscitated if the guidelines had been followed.

Chapter 2.2: Traumatic Cardiac Arrest: Is treatment futile?

2.2.1 INTRODUCTION

The following study was carried out to test the hypothesis that aggressive treatment of traumatic cardiac arrest in a physician-led system is not futile and may result in neurologically intact survivors. In addition I wished to determine whether outcome varied by patient subgroup. I thus sought to determine the long term survival rates for patients suffering pre-hospital traumatic cardiac arrest who were attended by a physician-led trauma service, and to characterise those who survived to hospital discharge. The records of any surviving patients were examined to explore the validity of the NAEMSP / ACS guidelines in UK physician-led practice. The study was carried out for adults and separately for children on the basis that the injury mechanism, causes and frequency of paediatric traumatic cardiac arrest are potentially different.

2.2.2 METHODS

The study was based in London's Air Ambulance in which dispatch criteria are used to target patients with severe trauma. The LAA medical team usually arrive shortly after ground ambulance crews, sometimes at the same time and rarely first. Where a ground ambulance crew arrive first a Basic Life Support (BLS) or Advanced Life Support (ALS) protocol is followed depending on the level of ambulance service provider (emergency medical technician or paramedic). When the LAA medical team arrive they work with the ground crew work to achieve the following (some of which may have already been achieved) as indicated:

- Oxygenation / definitive airway
- Effective ventilation
- Formal bilateral chest decompression
- IV access / fluid bolus
- Advanced Cardiac Life Support
- Termination of resuscitation if no response to resuscitation is observed after 20 minutes of resuscitation

Where ‘medical’ cardiac arrest is a possibility immediate defibrillation is considered. If local criteria for on-scene thoracotomy are met (50), this procedure is commenced without delay.

The attending physician records all interventions carried out in the pre-hospital phase of care on a Microsoft ACCESS™ (Microsoft, Redmond Washington, USA) database.

A retrospective trauma database review was conducted to identify adult and paediatric patients who had pre-hospital cardiopulmonary resuscitation (CPR) between July 1994 and June 2004. The database was searched using the intervention categories ‘CPR’, with missing records sought by search for ’Defibrillation’, ’Adrenaline‘ and ’Pre-hospital Thoracotomy‘ and outcome category ’Pre-hospital death‘.

Inclusion Criteria

Data were evaluated for patients transferred directly from the accident scene. Patients who were confirmed dead on scene and not transported to hospital were included, as were those who had suffered cardiac arrest as a result of burns, hanging, traumatic asphyxia, electrocution and drowning. Excluded were

interhospital transfers, and rare isolated cases of medical cardiac arrest to which the service had been dispatched in special circumstances (e.g. where access to a patient was difficult).

The primary outcome measure was survival to hospital discharge. Separate analysis was performed for adults and for children (defined as age <16 years of age), in whom causes of TCA may differ, and for whom resuscitative efforts are not usually terminated until arrival in the emergency department.

2.2.3 RESULTS: ADULT TRAUMATIC CARDIAC ARREST

In the 10-year study period, a total of 12,086 trauma patients were attended by the service of which 10,352 were adults and 1734 were children. Nine hundred and nine adult patients required pre-hospital CPR. Seven hundred and forty patients (81.4%) died in the pre-hospital phase or in the emergency department. One hundred and thirty-one patients (14.4%) survived to discharge from the emergency department, of whom 68 (7.5%) survived to hospital discharge. The outcome could not be determined for 38 patients (4.2%) who were triaged to other hospitals (Figure 2.2). Using medical notes and database information, I attempted to determine the main cause of the cardiac arrest for the survivors. Of those who suffered blunt trauma, six had cervical spine injuries, six had isolated head injuries, six had tension pneumothorax and nine had traumatic asphyxia.

Eight of the survivors of penetrating trauma had cardiac tamponade at pre-hospital thoracotomy. Hypovolaemia was considered to be the cause of cardiac arrest in the one other survivor sustaining penetrating injury. One neurologically

intact survivor underwent an on scene thoracotomy following blunt chest trauma.

Thirteen (36%) of the 36 surviving patients who were in cardiac arrest as a direct consequence of blunt or penetrating trauma breeched the NAEMSP/ACSCOT guidelines (70). Resuscitation might have been withheld or terminated in these patients if the guidelines had been strictly observed. Five blunt trauma patients and one patient with penetrating trauma were found to be apnoeic, pulseless, and without organised ECG activity or signs of life on our arrival. A further 7 patients underwent more than 15 minutes of CPR following EMS-witnessed arrest and survived. In addition four blunt trauma survivors were found to be apnoeic and pulseless on initial assessment but ECG rhythm was not recorded. It is possible that a number of these patients would also have breeched the guidelines.

Figure 2.2 Adult TCA Survival

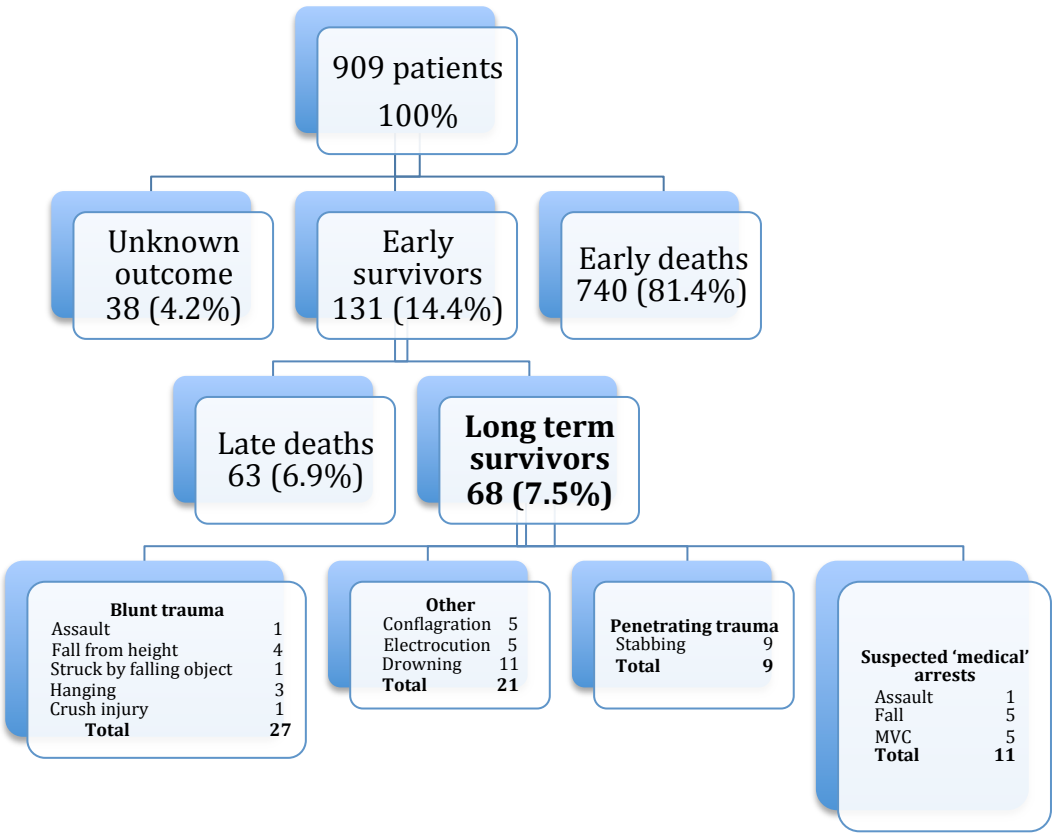


Table 2.3 Mechanism of injury in adult TCA survivors

Mechanism of Injury	Number	Survivors (%)
Blunt Trauma (assault, falls, under train, MVC, struck by falling object, other)	542	**18 (3.3%)**
Asphyxial Injury (conflagration, drowning, electrocution, traumatic asphyxia, hanging)	176	**30 (17.0%)**
'Medical' + Trauma	39	**11 (28.2%)**
Penetrating Trauma	**114**	**9 (7.9%)**

(+ 38 patients who were lost to follow up) MVC – Motor Vehicle Collision

2.2.4 RESULTS: PAEDIATRIC TRAUMATIC CARDIAC ARREST

In the ten-year study period, 1734 children were attended and eighty (4.6%) required pre-hospital CPR on scene or during transport to hospital. Of these, 19 (23.75%) survived to discharge from the emergency department. Seven children (8.75 %) survived to be discharged from hospital; their mean age was 5.7 years (range 2-11). Three children were functionally normal at the time of discharge. Full neurological outcome data were unavailable for the remaining survivors. Twelve children died during inpatient stay. The average survival of this subgroup was two days (Range 1 – 6 SD 1.52); five patients died within the first 24 hours.

Fifty patients (62.5%) had sustained blunt trauma, including two patients who were suspected to have had a medical cardiac arrest, which most likely occurred before, and resulted in, their trauma. Road traffic collision (RTC) was the mechanism of injury in 33 children (41.3%). Other mechanisms of blunt trauma were fall from height, air crash, assault, struck by a falling object, and a case of non-accidental injury. All seven patients (8.75%) with penetrating trauma had stabbing injuries. Twenty-three patients (28.75%) sustained hypoxic insults (hanging, drowning, and burns / smoke inhalation) [Figure 2.4].

Four patients (5.0%) survived to hospital discharge following blunt trauma. One survivor had spinal cord injury, and two patients sustained traumatic asphyxia following crush injury to the chest or airway obstruction. In one survivor with a background of congenital heart disease it is probable that the cardiac arrest was medical in origin but it is unclear whether it was the cause, or a consequence, of his trauma. Three children (3.75%) survived following a hypoxic mechanism of injury that resulted in cardiac arrest. The mechanism of injury in one of these

cases was near drowning; the other two children arrested following burns / smoke inhalation.

There were no survivors of penetrating trauma. Thoracotomy was performed in four of the seven patients with penetrating injury. It was not carried out in the remaining three children because they did not meet local indications for this procedure (50). The mean scene time for the study population was 26.4 minutes (range 14-51, SD 12.6) and mean transport time was 6.4 minutes (Range 1-15 SD 3.5).

Figure 2.3 Paediatric TCA survival

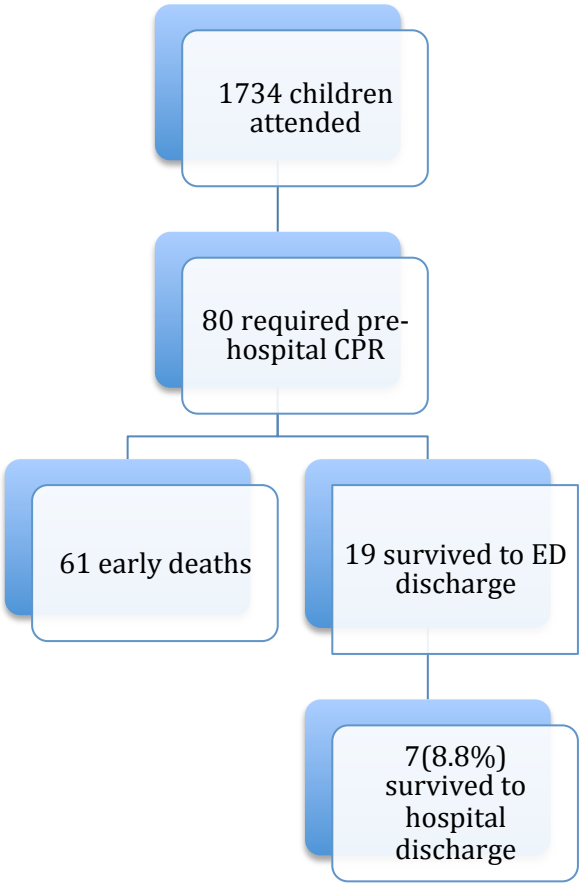
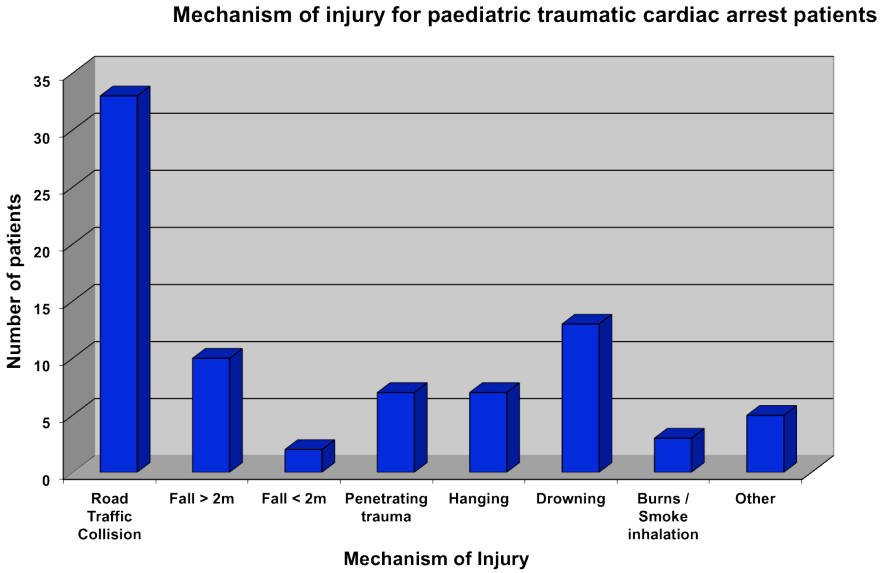


Figure 2.4



2.2.5 DISCUSSION

Adult patients

This study is the largest series of TCA published to date. It demonstrates that in the setting of an urban physician-led system, pre-hospital resuscitation is associated with a long term survival rate of 7.5% for patients with cardiac arrest associated with trauma. Attendance of our pre-hospital team guarantees the presence of a physician and usually at least three rescuers, which may improve outcome. However two other studies published after production of the 2003 US treatment guidelines show remarkably similar survival rates of 7.6% (187 patients) (54) and 7.6% (195 patients) (51) with non-physician EMS systems. It is unclear why these recent results appear to be better than those published before the US National Association of EMS (NAEMSP) physicians guidelines (70). The futility of resuscitation in traumatic cardiac resuscitation has often been stressed. If my data, and those reported in other smaller publications from

the same period (51,54) are truly representative of traumatic cardiac arrest outcome then outcome from traumatic cardiac arrest, while still very poor, can be as good as (or better than) the outcome from out-of-hospital cardiac arrest of any cause in the same period (75).

Examination of the characteristics of the survivors revealed that certain subgroups of patients did better than others. The survival rate of patients whose cardiac arrest was the result of hypoxemia (hanging, drowning, electrocution, conflagration, traumatic asphyxia) was 17%. The relatively good outcome in this subgroup is confirmed in another recent study (32) and the EMSP /ACSCOT guidelines do emphasize that particular attention should be paid to this group.

Another group associated with a relatively good outcome includes those patients with penetrating trauma who met the local criteria for, and subsequently underwent, pre-hospital thoracotomy. Eight survivors (8.6%) from our series had a thoracotomy performed on scene, 5 of whom were subsequently neurologically normal. This intervention will be examined in more detail in the next chapter. Six patients had cardiac arrest after cervical spine injuries. Although I do not have long term morbidity data for these patients, their notes suggest severe high spinal trauma. It seems likely that some of these patients would have had a primary respiratory arrest secondary to high spinal injury and progressed to cardiac arrest. Resuscitation was successful in six patients with isolated head injuries. Unfortunately I have not established the long term functional outcome in all of these patients, but poor neurological outcome has been demonstrated in similar patient groups (70).

Six patients had a return of cardiac output after decompression of a tension pneumothorax. This emphasizes the importance of chest decompression in

patients with traumatic cardiac arrest. The subgroup with the most strikingly poor outcome comprised those where TCA on scene appeared due to hypovolaemia. Only one patient survived this scenario. The hypovolaemic trauma patient is possibly seen as the 'typical' traumatic cardiac arrest by many healthcare providers and this study confirms the almost universally fatal outcome in this group.

Thirteen survivors breeched the NAEMSP/ACSCOT guidelines regarding the withholding or termination of resuscitation efforts in traumatic cardiac arrest. The guidelines on which our patients breeched related to the withholding of resuscitation:

- In the blunt trauma patient who is apnoeic, pulseless, and without organized ECG activity upon the arrival of EMS at the scene (n=5)
- In the victim of penetrating trauma found apnoeic and pulseless by EMS, and lacking other signs of life, such as pupillary reflexes, spontaneous movement, or organized ECG activity (n=1), and
- Termination of resuscitation efforts in trauma patients with EMS-witnessed cardiopulmonary arrest after 15 minutes of unsuccessful resuscitation and cardiopulmonary resuscitation. (n=7)

A recent smaller series which described 184 pre-hospital traumatic cardiac arrests (54) demonstrated breeches in the same areas. Most of the 14 survivors in that study breeched one of the time-related guidelines. When these data were published in the Annals of Emergency Medicine (76), editorial comment was made on this study which stated that 'This study demonstrates that strict adherence to the guidelines by physicians in the field might result in a few

potentially salvageable patients being denied lifesaving measures. Results in paramedic-based systems would be expected to be less successful.' The fact that neurologically intact survival can occur in some who could be denied resuscitation based on the 2003 guidelines illustrates how difficult it is to make recommendations on the basis of low level, often conflicting, evidence. Equally the production of guidelines that resulted in large numbers of severely neurologically disabled individuals would be controversial.

Paediatric patients

Paediatric cardiac arrest is an infrequent event, accounting for only 2% of all out-of-hospital cardiac arrests (62). However, a review published in 2005 suggested that almost 22% of cardiac arrests in children are associated with trauma (68), making this one of the most common causes of pre-hospital cardiac arrest and death between the ages of one and sixteen years (59,61). Guidelines for withholding or terminating resuscitation in traumatic cardiac arrest do not include children because of the lack of data on the subject (70). Most successfully resuscitated paediatric cardiac arrest victims are those who receive CPR in the pre-hospital phase (65). Ideally, providers of emergency care should be aware of patient sub-groups in whom aggressive resuscitation efforts may produce a good outcome.

The survival rate for children sustaining cardiac arrest associated with trauma in our study is 8.75%. As with our adult survival rates this figure does need to be compared with reported rates of survival following out-of-hospital cardiac arrest of all causes (5 - 8.4%) (75,77). Three patients survived without neurological deficit. Two of the neurologically intact survivors sustained an asphyxial

mechanism of injury secondary to blunt trauma. The third intact survivor suffered burns / smoke inhalation. In the other survivors full details of neurological outcome could not be obtained (all were taken to hospitals which were not the base hospital for this service).

Previous work has suggested that cardiac arrest in children is often caused by bleeding or prolonged hypoxaemia (60). Our data do suggest that some of the small number of survivors do originate from a group with mechanism of injury consistent with hypoxaemia and the patient group with the highest survival rate (13.0%, 3 of 23 children) included those children who appeared to suffer cardiac arrest after becoming hypoxic. This finding is confirmed by another study, where four of the five surviving children had a hypoxic mechanism of injury (near drowning and hanging) (47). Similar results have been observed in studies of adults (32) and our adult study also reported higher survival rates for this patient group (76). Patients sustaining blunt trauma may experience a period of apnoea precipitating a respiratory arrest, which progresses to cardiac arrest. If our 'hypoxic' subgroup is extended to cover all hypoxic insults including hanging, drowning, burns / smoke inhalation, and those with traumatic asphyxia secondary to blunt trauma, then the majority of our survivors fall into this category (5 of the 7 survivors). Children in this subgroup may particularly benefit from aggressive pre-hospital resuscitation.

In my series, no children who had a cardiac arrest following penetrating trauma survived. Hypovolaemic cardiac arrest is often associated with a poor outcome (59,60) and this was demonstrated clearly in our adult TCA population (59,60,76). The high rate of bleeding associated with hypovolaemic cardiac arrest in the pre-hospital phase is unlikely to respond to conventional CPR. In

contrast, when apnoea precedes cardiac arrest, provision of adequate oxygenation may restore a spontaneous circulation. The survival rate for children who sustained blunt trauma was 5.0%, which is comparable to other studies (0-4.8%) (56,60,61).

Unfortunately, data on the neurological outcome of the survivors was incomplete. In addition the presenting cardiac rhythm was not always documented. I could not therefore correlate presenting rhythm with survival (previous work has shown that ventricular fibrillation is associated with a more favourable outcome (66)).

The survival rate from TCA might be expected to be higher where a physician-led pre-hospital response is provided. The majority of paramedics rarely encounter children in cardiac arrest because it is an uncommon event. The presence of a physician on scene enables interventions that are outside the scope of paramedic practice, to be undertaken early after injury. However this will only provide benefit if the interventions offered are those that influence survival. There is a suggestion that the survivors in our study required urgent ventilation and oxygenation on scene that should be within the remit of UK paramedic care. There is also potential for survival improvement with the presence of more, or more effective rescuers. The scene times documented in this study (mean 26.4 minutes) are no longer than those reported by ‘paramedic-only’ systems (78). Thus, the time taken for the patient to receive advanced treatment is reduced without delaying transfer times to hospital.

There are no specific guidelines for the management of children in cardiac arrest secondary to trauma. The guidelines from the USA regarding withholding or termination of resuscitation in pre-hospital traumatic cardiopulmonary arrest

specifically exclude children because supporting evidence is lacking (70). In the ten-year study period, paediatric advanced life support undertaken by London's Air Ambulance personnel complied with the European Resuscitation Council (ERC) guidelines (79,80).The 2005 ERC guidelines has included a simple algorithm for paediatric basic life support which is directed at healthcare professionals. The section from these guidelines focussing on cardiac arrest in special circumstances also addresses the management of trauma patients in cardiac arrest (81).

This relatively large adult study confirms the outcome of traumatic cardiac arrest demonstrated in recent smaller studies. Outcome is still poor but, for reasons that are unclear, better than previously described. Survivors are found in several subgroups (e.g. asphyxial injuries, penetrating chest trauma with immediate thoracotomy, neurological injuries, tension pneumothorax) but cardiac arrest secondary to hypovolaemia is virtually always fatal. This may highlight areas for further research. Recent guidelines published on withholding resuscitation in traumatic cardiac arrest should be applied with caution since survivors who may have breeched the guidelines have now been described in two studies.

Our paediatric study confirms the poor outcome for children receiving pre-hospital CPR for cardiac arrest associated with trauma. However the survival rate is at least as good as previously reported by most other similar studies. Survivors appear to come from the subgroup of patients suffering from a hypoxic insult. Children with hypoxic insults appear to have a better chance of survival, and those with hypovolaemic arrest rarely survive. Three of seven surviving children had a good neurological outcome. Targeted aggressive out-

of-hospital resuscitation may produce good outcomes in some identifiable patient groups but evidence based guidelines are difficult to produce on the basis of limited cases published in highly heterogeneous studies.

2.2.6 STUDY LIMITATIONS

This study relied upon retrospective observational data. The related grade of evidence is thus low when considered in the context of evidence based medicine guidance (82). However at the time of publication virtually all of the available data on the survival from traumatic cardiac arrest were derived from retrospective database studies. This study was the largest series published on the subject. Follow up data were unavailable on 4.2% of patients and a major drawback of this study is the lack of information on the functional outcome of the survivors. Some of the survivors may have survived in a poor neurological state. Injury severity scores were not available on all patients but the relevance of applying this score to patients who are post cardiac arrest is questionable (37). Physicians attended all of the patients in this study and the interventions available to them are clearly described. The guidelines do not suggest that they should only be applied in specific types of EMS systems but they do suggest that they should be 'individualized for each EMS system'. The results reported in this study may not be easily extrapolated to systems with different levels of pre-hospital care providers.

My paediatric series is the largest of its type from the UK but it includes relatively few subjects. The study is of local interest but adds little to the overall understanding and potential improvement in the treatment of paediatric cardiac arrest. The low numbers of paediatric TCA in a high volume trauma system with

a large population demonstrates that to produce data on which to base treatment and survival predictions on (particularly in mechanism sub-groups) is likely to require national and international data collaborations. National data registries may provide the necessary data but only where data capture is high. National trauma data registries are increasingly utilised and efforts have been made to standardise the data collection between key registries (83). Useful data on which guidelines could be based are only likely to be produced with the amalgamation of high quality data with functional outcome information from large national trauma databases.

Chapter 3.1 Pre-hospital thoracotomy: Does it have a role?

2.3.1 INTRODUCTION

Emergency thoracotomy is a well established emergency department procedure for cardiac arrest associated with penetrating trauma. My adult study on traumatic cardiac arrest made clear that a significant proportion of the limited number of survivors of out of hospital traumatic cardiac arrest in our service were those that had on-scene thoracotomy. The procedure has been associated with some of the better survival rates in selected groups of patients with TCA (35) and where TCA occurs after penetrating injury proximity to surgical intervention does appear to dictate the likelihood of survival following emergency department thoracotomy. In one study, survival rates for emergency department thoracotomy were 0%, 4% and 19% for patients arresting on scene, in an ambulance or in the emergency department (ED) respectively (84). The outlook for patients who have cardiac arrest documented on-scene is bleak and several other studies have also reported 100% mortality in this patient group (85-88). In 1994 the first case report of successful pre-hospital thoracotomy was published (89). The operator was a surgeon observing pre-hospital care. The report discussed the possible role of surgeon performed pre-hospital thoracotomy and the unlikely possibility of staffing pre-hospital services with surgical residents. However it concluded that pre-hospital thoracotomy ‘should not be adopted as a standard component of pre-hospital care’ without properly conducted further studies. Published USA guidelines for the treatment of cardiac arrest associated with trauma took a similar view (70) and stated that ‘thoracotomy is outside the remit of pre-hospital care’. In contrast to the US, in many European pre-hospital systems the use of physicians has been routine for

many years. Although the use of surgeons in pre-hospital care is rare and unlikely to ever be significant, senior trainees and consultants in anaesthesia and emergency medicine regularly attend patients with penetrating trauma. Pre-hospital thoracotomy has been carried out in our system for many years. The first case resulting in survival was carried out in 1993 (90) and others followed (50,76).

I thus set out to establish the survival rates of patients with stab wounds to the chest who had on-scene thoracotomy after cardiac arrest in an urban physician-led pre-hospital service. Given that the incidence of penetrating trauma in the population served by an EMS service is likely to be the most important variable driving demand, I also investigated temporal trends in presentation with penetrating trauma.

2.3.2 METHODS

A fifteen year retrospective database search was carried out in the LAA pre-hospital physician based trauma service (see Section 1.2.2). Standard operating procedures are in place to promote an aggressive approach to rapid transfer of patients with penetrating trauma who still have a cardiac output to appropriate centres. These consisted of the limited number of cardiothoracic centres available in London until the commissioning of four London major trauma centres in 2010, to which all penetrating chest trauma is now transferred and in which emergency department resuscitative thoracotomy is available. Scene times must be short and any interventions are carried out on route to hospital. If the criteria for pre-hospital thoracotomy are met (penetrating chest injury with cardiac arrest which occurs less than ten minutes before team arrival, at least five minutes transport time from an emergency department),

then operation is carried out immediately. Patients are then rapidly transported to an appropriate hospital (during this study period usually our base hospital) where the patient is handed over to an emergency physician-led trauma team and attending surgeon.

Patients included had knife wounds to the chest or epigastrium and had thoracotomy carried out according to the local service Standard Operating Procedure. The operative technique used has been previously described (91). Patients who had thoracotomy carried out for gunshot wounds or blunt trauma or any cases where the criteria for intervention were not met, were excluded.

2.3.3 RESULTS

Seventy one patients who had on-scene thoracotomies met the inclusion criteria. Thirteen patients (18%) survived to hospital discharge (Table 2.4). Neurological outcome was good in eleven patients and poor in two. Ten had one wound and three had multiple wounds. Cardiac rhythm prior to thoracotomy was asystole in four patients, pulseless electrical activity in five and in the remaining four it was not recorded. At operation all survivors had cardiac tamponade. In addition, ten had a single right ventricular wound, one had two right ventricular wounds, one had biventricular wounds and one had a thoracic aortic injury. The medical team were in attendance when seven of the survivors suffered cardiac arrest (all good neurological outcome), arrived in the first 5 minutes after arrest in three patients (all good neurological outcome), 5-10 minutes after arrest in two patients (1 poor neurological outcome) and an unknown period in one (poor neurological outcome). Of the thirteen survivors, seven thoracotomies were carried out by doctors with a background in emergency medicine and six by doctors with an anaesthesia background.

Table 2.4 Pre-hospital thoracotomy survivors

Survivor	Gender	Age	Injury (site of stab wound)	Time from cardiac arrest to team attending (minutes)	Cardiac rhythm before intervention	Neurological outcome	Hospital length of stay
1	m	34	RV with tamponade	In attendance	A	Good	25
2	m	48	RV Ventricular entry + exit wound with tamponade	5-6	NA	Poor	130
3	m	23	RV with tamponade	3	PEA	Good	11
4	m	22	RV with tamponade	In attendance	PEA	Good	6
5	m	16	RV with tamponade	In attendance	PEA	Good	4
6	m	17	RV with tamponade	3	PEA	Good	7
7	m	34	RV with tamponade	In attendance	A	Good	NA
8	m	18	RV with tamponade	N/A	PEA	Impaired	13
9	m	48	RV with tamponade	5-10	A	Poor	29
10	m	41	RV with tamponade	In attendance	A	Good	6
11	m	40	RV with tamponade	In attendance	A	Good	12
12	m	19	RV with tamponade	3	NA	Good	25
13	m	15	Thoracic aorta and tamponade	In attendance	PEA	Good	7

RV = Right Ventricle, A= Asystole, PEA= Pulseless Electrical Activity, NA= Data not available

2.3.4 DISCUSSION

Survival seems most likely in patients with stab wounds and cardiac arrest secondary to pericardial tamponade. Good neurological outcome was more likely when thoracotomy was carried out soon after arrest. The cardiac rhythm and base specialty of the operator seemed less important. The small number of survivors makes robust generalisations difficult.

Ideally emergency thoracotomy should be performed by experienced surgeons in the operating room. Unfortunately those patients who suffer cardiac arrest on scene after penetrating trauma in our EMS system rarely, if ever, survive to the operating theatre. I recognize that pre-hospital thoracotomy is a significant undertaking which is only considered when on-scene cardiac arrest following

penetrating chest trauma has occurred. My results demonstrate that where injuries are straightforward and a physician is in attendance close to the time of cardiac arrest a number of neurologically intact survivors can be expected. Other pre-hospital services have reported a further two neurologically intact survivors after pre-hospital thoracotomy, one from Hampshire, UK and the other from Madrid, Spain (92,93). Thoracotomy for blunt trauma is more likely to require technical surgical skills than relief of tamponade in penetrating trauma and results are usually very poor even when performed in hospital. We do not currently perform the procedure for blunt trauma. This approach is supported by a recent series of thirty four pre-hospital thoracotomies performed for blunt trauma in Japan where no survivors were reported (94). A number of patients with gunshot wounds have had the procedure but, to date, none have survived. Although numbers are small, this patient subgroup has a survival rate of 18%. This is considerably better than previously published rates of survival in traumatic cardiac arrest that were discussed in the previous chapters (30,31,36,49,54,76).

The rate of severe neurological morbidity in the survivors in pre-hospital thoracotomy survivors (15%) is lower than in any other reported survivor subgroup after survival from TCA (36,49,95).

The technique that we use for the procedure (91) has been influenced by a human factors approach. It is simple, rapid, gives excellent exposure and is easily taught. The equipment required is minimal, lightweight and familiar to non-surgeons. While surgical experience would be preferable in those performing this procedure there is no likelihood of surgeons providing pre-hospital care in our system. We believe that the procedure can only be

performed in a trauma system that has the support and immediate availability of appropriate surgeons and critical care specialists. In contrast to the USA, many pre-hospital care services in Europe are physician-led. It seems very unlikely that this intervention could be performed in non-physician systems.

In keeping with post – out of hospital cardiac arrest guidelines for patients with ventricular fibrillation (28) we believe that patients who have had thoracotomy after cardiac arrest should have induced moderate hypothermia for 24 hours and slow re-warming. There is however no evidence that this intervention is beneficial in this specific patient group and with small patient numbers it is unlikely that evidence to support this approach will available in the foreseeable future.

Complex pre-hospital interventions in pre-hospital care require careful governance. Pre-hospital anaesthesia has been under intense scrutiny in the US (96,97) and USA guidelines have suggested that the intervention should only be carried out in systems which provide medical direction and supervision, comprehensive training and continuing education, appropriate equipment, standardized protocols, quality assurance and performance review (98). A similar approach would seem appropriate for those systems performing pre-hospital thoracotomy and we see these standards as an absolute minimum to ensure appropriate use of an aggressive resuscitation intervention. Resistance from surgeons to the idea of non-surgeons performing this procedure may be reduced when it is realised that most of these patients would never come into contact with a surgeon before death. Ideally a cardiothoracic or trauma surgeon in an operating theatre should operate on all victims of penetrating chest trauma who require surgery. Unfortunately with only a few minutes to relieve a cardiac

tamponade after cardiac arrest this standard of care is not possible for some patients. The sub-section of the European Resuscitation Council (ERC) guidelines on trauma in cardiac arrest were written by the author of this thesis and mention pre-hospital thoracotomy in 2005 and include the evidence from our service in 2010 (81,99). The American Heart Association (AHA) guidelines concentrate more on standard BLS and ALS and reference the NAEMSP guidelines that have been discussed in detail in the previous chapter. However a leading US trauma surgeon has recently commented on the fact that the prognosis for patients arriving with penetrating trauma and CPR is so poor that with the correct levels of governance provided by a trauma system pre-hospital thoracotomy may have a role (100). This is a major change in attitude and may signal wider acceptance of a controversial intervention. The data presented do not constitute high level evidence. However, they do clearly demonstrate that the comment in the NAEMSP guidelines which are referenced in the current 2010 American Heart Association guidelines (namely, 'in the case of penetrating trauma patients without vital signs. ...will not survive even with the most aggressive of therapies') is simply not true. A randomised controlled trial of pre-hospital thoracotomy vs. transport to hospital and thoracotomy in the emergency department is unlikely to be ethically approved in a system where pre-hospital thoracotomy is already performed since the evidence suggests 100% mortality for those who do not get the intervention. However a case controlled study recruiting patients with the indications for on scene thoracotomy in areas where the intervention is and is not available would provide better levels of evidence on which to judge benefit.

With high governance standards in place we are confident that our system and other similar systems will continue to produce a small number of survivors in a patient group which previously had a virtually guaranteed mortality.

The role of pre-hospital thoracotomy and the design of pre-hospital responses to penetrating trauma depend very much on the frequency of penetrating trauma in the target population. We anecdotally believed that the rate of penetrating trauma in our target population was rising and the next chapter describes how we established that this was the case.

Chapter 4.1 The rate of penetrating trauma in London

2.4.1 INTRODUCTION

There is much speculation in the media that morbidity and mortality related to knife and gun-crime in the United Kingdom (UK) has surged dramatically over recent years (101,102). One thousand, two hundred knife attacks were reported in London in 2005 (103) and this had increased to 3403 in 2012 (104). The Times newspaper described increases of between 55 and 73% in 'knife-crime' in England and Wales in 2006 (105). Data from the Office for National Statistics demonstrate that violent crime against the person, involving firearms, increased by 135% between 1997/98 and 2001/02 (106). Metropolitan Police Service (MPS) figures for London estimated that 52 teenagers are victims of knife crime each week (107). It is unclear whether this reported trend translates into a clinically significant increase for the medical emergency services.

This study was performed to establish whether the reported increase in UK penetrating crime translates into an increase in the penetrating trauma caseload of our London-based pre-hospital trauma service. This has implications in understanding the demand for the provision of penetrating trauma related interventions such as resuscitative thoracotomy.

2.4.2 METHODS

A retrospective review of prospectively collected data from the London Air Ambulance trauma database was conducted. The trauma database contains comprehensive medical records for all patients attended. Data are entered by the medical team after each mission. All patients with deliberate penetrating injury who were attended by the service between January 1, 1991 and December 31, 2006 were identified. Patients who died in the pre-hospital phase

and paediatric patients (aged 16 years or less) were included. The primary outcome measure was the number of cases of deliberate penetrating trauma attended over the study period. The mortality rate was also recorded. Linear regression analysis was performed, using 'Stats Direct' (StatsDirect™ Cheshire UK), in order to identify the trend of the results obtained. The significance level of the test was set at 5%. Further calculations were performed to establish how the actual annual figures for penetrating trauma related to the first year of the study. In addition, local and national statistics for penetrating trauma were reviewed from the Trauma Audit and Research Network (TARN), the Home Office, the British Crime Survey, and the Metropolitan Police Service (MPS), in order to establish whether similar trends are present in other data sets. Data was accessed from these sources via public databases or through personal communication.

2.4.3 RESULTS

Over the 16-year study period 16,068 patients were attended. Of these, 1564 patients (9.7%) sustained penetrating injury and 14,504 (90.3%) blunt trauma. During the study period, a median of 9.9% of patients attended each year had deliberate penetrating trauma (range 2 – 17.2%). The proportion of penetrating injury increased significantly by 0.7% ($p = 0.0002$; 95% confidence interval (CI) = 0.4 to 0.9), each year. 91.7% of penetrating trauma victims were male. There were 1358 patients (86.8%) with stabbing injuries, and 206 (13.2%) had been shot. The study population included 92 children (5.9%) (Table 2.5).

There was an annual increase of 20.5% in the number of cases of intentional penetrating trauma attended over the 16-year study period. Stabbings

increased by 23.2% year on year. This figure translates into an actual increase of 8.9 stabbings annually ($p < 0.0001$; 95% CI = 5.9 to 12.0). Gunshot wounds (GSW) increased by 11.0%, or by 1.4 shootings ($p = 0.0003$; 95% CI = 0.8 to 2.0) [Figure 2.5]. The amount of blunt trauma attended over the study period increased by 2.7% year on year but the proportion (Blunt: Penetrating) reduced by 10% ($p= 0.01$) [Figure 2.6]. With respect to the first year of the study (where 1991 = 100%), there was an overall increase of 1643% in penetrating trauma; blunt trauma increased by 150%.

The number of children sustaining penetrating trauma increased annually by 29% over 14 years of the study, equivalent to one patient per year ($p = 0.0026$). No paediatric penetrating trauma was reported in 1991 or 1992. The median number of children sustaining penetrating injury each year was 5 (range 1 – 28). Accurate mortality data were only available after the year 2000, and demonstrated a median of 17 deaths / year (range 14 – 23), with an overall mortality rate of 12.6% (range 10.0% to 19.3%).

Results from the TARN database demonstrated a mean of 267 stabbings (range 173 – 337), and 56 GSW (range 28 – 76) per annum from 1998 to 2004. An additional 21.5 stabbings ($p = 0.044$) and 5.6 GSW ($p = 0.065$) were reported to TARN annually (3) over the seven-year period. These figures translate into a non-significant year on year increase of 8.8% in the number of stabbings, and 11.6% in the number of shootings.

Home Office data for England and Wales reported a mean of 225 homicides / year associated with a sharp instrument between 1994 and 2005 (range 197 – 266). There was little change in the average number of homicides recorded between 1994 ($n = 231$) and 2005 ($n = 236$) ($p = 0.17$). Firearm-related

homicide increased from 63 cases in 1994 to 77 cases in 2005 (p = 0.05), with an average of 65 cases per year (range 46 – 97) (108). Data from the British Crime Survey (BCS) conducted in England and Wales revealed a 3% reduction in wounding associated with knife use; 9% in 1995 compared with 6% in 2004/5 (109). MPS figures recorded 3324 cases of gun-related crime in November 2006 compared with 3195 instances in November 2007 (110).

Table 2.5 Trauma caseload attended by LAA 1991-2006

Year	Number of trauma Patients attended	Number (%) of Patients with penetrating trauma	Number of stabbings	Number of shootings	Paediatric patients
1991	691	14 (2.0)	9	5	0
1992	673	14 (2.1)	12	2	0
1993	812	49 (6.0)	46	3	1
1994	826	89 (10.8)	83	6	3
1995	925	97 (10.5)	83	14	6
1996	1053	73 (6.9)	64	9	4
1997	1044	97 (9.3)	87	10	3
1998	776	49 (6.3)	44	5	2
1999	846	77 (9.1)	65	12	3
2000	1128	117 (10.4)	99	18	6
2001	1139	88 (7.7)	71	17	6
2002	1067	135 (12.7)	106	29	9
2003	1258	134 (10.7)	115	19	6
2004	1252	131 (10.5)	122	9	4
2005	1335	170 (12.7)	146	24	11
2006	1340	230 (17.2)	206	24	28

Figure 2.5 Trends in Stabbings and Gunshot Wounds Attended by LAA

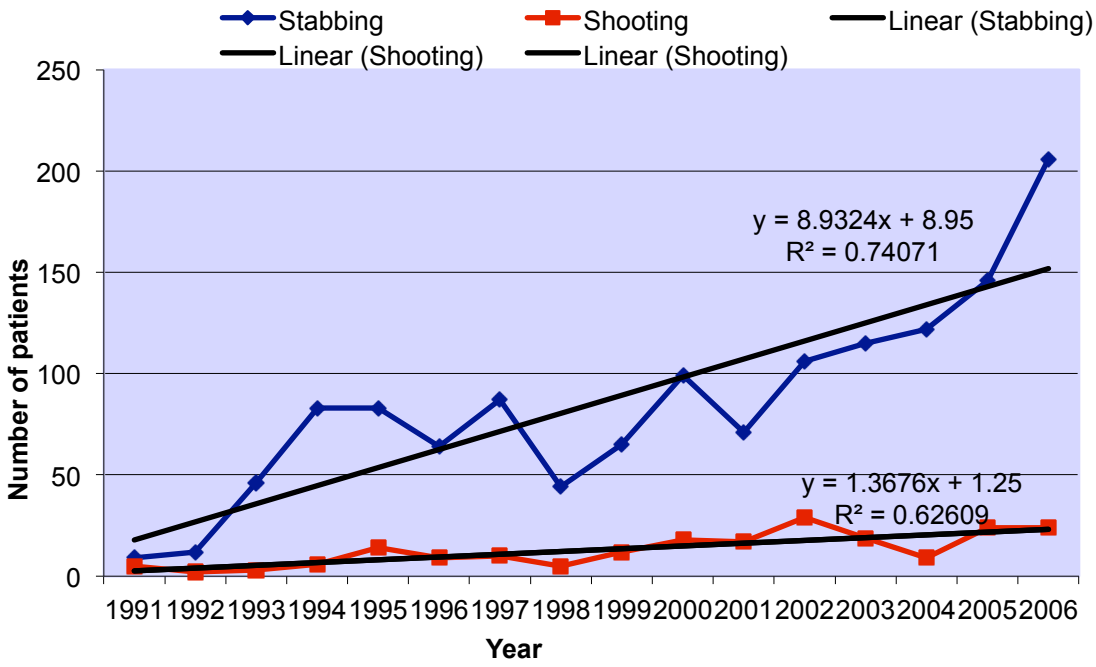
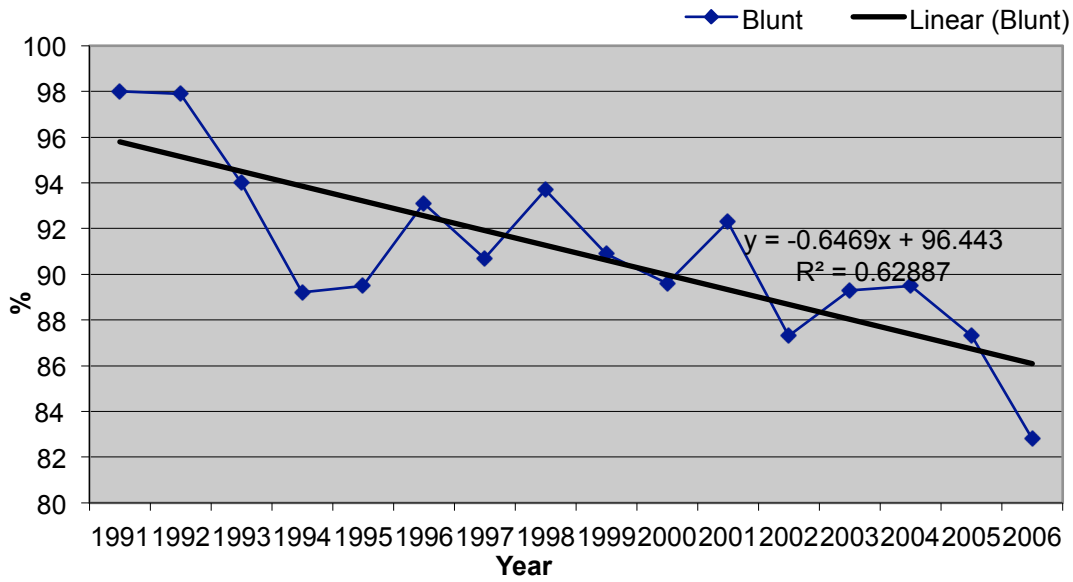


Figure 2.6 Percentage of Blunt trauma attended by LAA 1991-2006



2.4.4 DISCUSSION

These data demonstrated a substantial and statistically significant annual increase in the amount of penetrating trauma attended by a physician-led trauma service over a 16-year study period. This trend was observed for both the adult and paediatric population. Comparison with blunt trauma data further supports an increase in penetrating trauma that is not directly related to the annual increase in total caseload. Data analysis revealed a relatively low rate of annual increase for blunt trauma of 2.7%, whereas penetrating trauma increased year on year by 20.5%.

A recent in-hospital study conducted at my base major trauma centre also recorded an increase in the amount of penetrating trauma managed by the emergency department from 2004 – 2006 (111). It is probable that figures obtained for London are not representative of the UK as a whole. Higher rates of penetrating crime in London may be related to socioeconomic factors. Previous reports suggest that offenders and victims tend to come from lower socioeconomic groups (112). It is unlikely that the increase in intentional penetrating trauma observed in London over the study period can be attributed solely to an increase in population density. Data from the London Assembly and Greater London Authority only reported a 0.66% annual increase in the population of London between 1991 and 2006 (110).

The data obtained for this study come from a variety of sources, each of which reflects a different patient population. A single database encompassing all victims of UK penetrating trauma does not currently exist. LAA only responds to major trauma, with rare exception. Patients who do not meet dispatch criteria for

the service are therefore not included in the database. Similarly, data for those patients who present directly to the emergency department will not be recorded. Data from TARN demonstrated a small but significant annual increase in penetrating trauma over a seven-year period. TARN is a national database that produces regular reports detailing the prevalence and nature of traumatic injury. Submission of data is voluntary and at the time this study was conducted approximately 50% of UK hospitals participated. After the formation of trauma networks in the UK, submission of data to TARN has become mandatory for all hospitals receiving trauma patients and participation in the database has increased rapidly. Patients discharged within 24 hours of injury are not included in TARN analysis. While this excludes many with insignificant injury it is also likely to exclude many victims of stabbing (3).

Examination of data from criminal databases such as the Home Office, British Crime Survey, and Metropolitan Police Service produced conflicting results. It is probable these sources include incidents where knives or guns were used without actually causing injury, which may skew the data (107). The BCS reported a 3% reduction in injuries inflicted by knives (113). MPS data demonstrated a 3.9% reduction in firearm-related crime between November 2006 and November 2007 (114). Although specific MPS data for stabbings was not readily available, violent crime was reported to have fallen by 5.6% from 2006 - 2007. Homicide figures from the Home Office reported a small and non-significant rise in death attributable to knife and gun crime (108). These figures obviously only reflect mortality.

Published USA data have reported mortality rates from penetrating trauma of 8.9% - 11%. However, it is unclear whether these studies include patients who

were dead on scene (115,116). This study describes a median annual mortality rate for patients sustaining penetrating trauma between 2000 and 2006 of 12.6%. Patients pronounced life extinct on scene and those who died during the in-hospital phase were included. Dispatch criteria for LAA are designed to target only severe trauma cases or penetrating trauma in areas of the body associated with higher mortality.

This study demonstrates a significant and year on year increase in penetrating trauma attended by a London based pre-hospital trauma service. This is likely to indicate that in this EMS service the demand for pre-hospital resuscitative thoracotomy is likely to increase. The findings support the media reports of increasing knife and firearms crime but examination of other data sources reveal that it is very difficult to accurately confirm the presence or magnitude of any rise in deliberate penetrating trauma in the UK. These data relate to major injury only and do not include those incidents in which weapons were present but not used. Data from the TARN confirm a rise in UK penetrating trauma. Crime statistics suggest a fall in knife and gun-related crime. Although the question posed by this study was answered in that local demand for pre-hospital thoracotomy is likely to increase, it was interesting to note the difficulties of capturing accurate data on this high profile type of injury. There does not appear to be an accessible comprehensive database that accurately provides information on penetrating trauma in the UK.

2.4.5 STUDY LIMITATIONS

The study is a retrospective analysis of prospectively collected data, and is observational. Outcome data for the early part of the study were incomplete and

mortality rates could only be obtained for the last six years. The numbers of patients in the individual study groups were small in some instances (e.g. paediatric GSW). Crude data are presented and no allowances were made for minor changes in practice over the long study period.

2.4.6 STUDY FOLLOW UP 2013

The study described above was conducted soon after I registered for this MD. Data was reported on the period from 1991 until 2006 and was published in 2009 (117). The study concluded that there was an upward trend in penetrating trauma and predicted that this would continue and result in an increased demand for pre-hospital resuscitative thoracotomy. To establish whether these predictions were true the data collection was repeated in 2013 and included data from 2006 to 2012.

The results are shown in Figures 2.7,2.8 and 2.9. They demonstrate a continued rise in the number of penetrating trauma cases attended, a continued increase in the proportion of penetrating trauma attended and, as predicted, a rise in the number of pre-hospital thoracotomies performed.

Figure 2.7 Number of cases of penetrating trauma per year attended 1991 - 2012

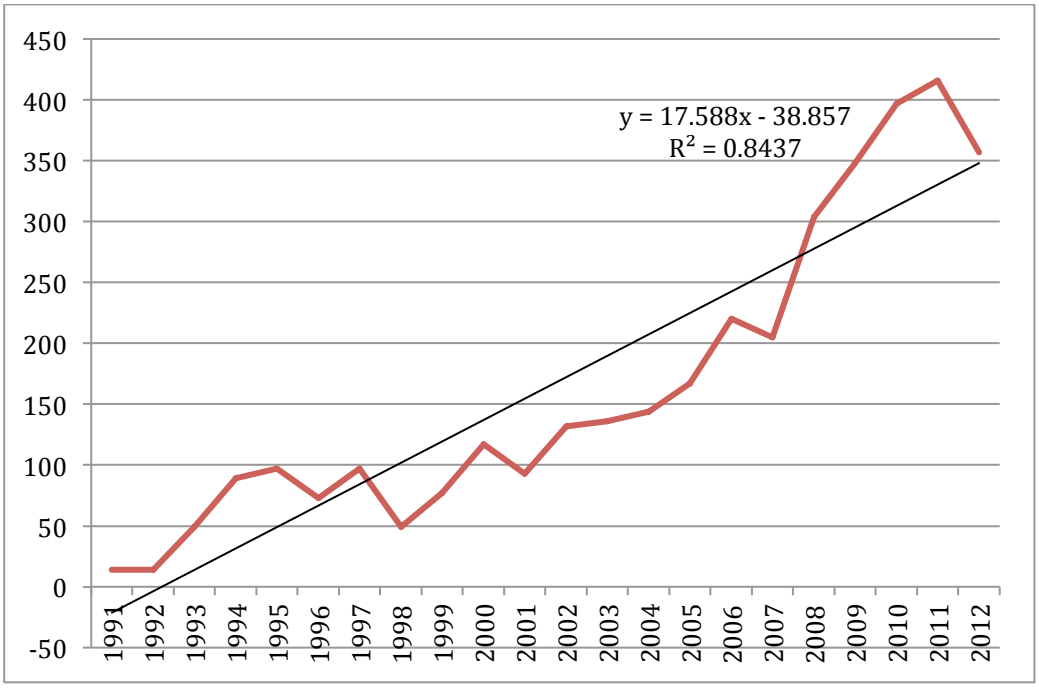


Figure 2.8 Percentage of penetrating trauma attended per year 1991-2012

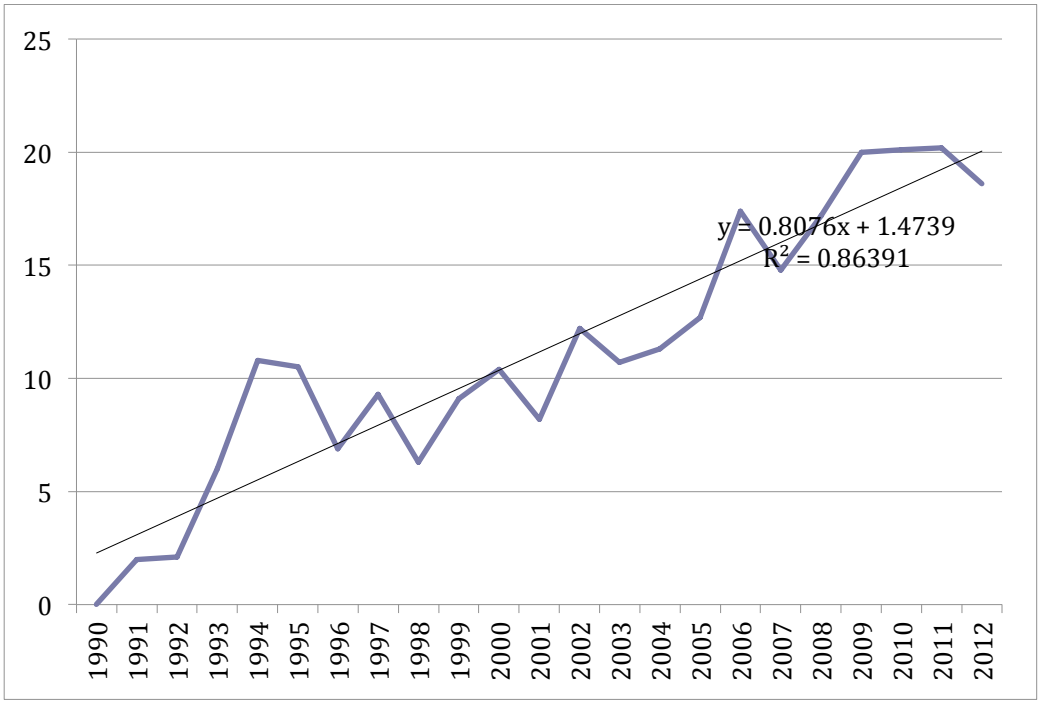
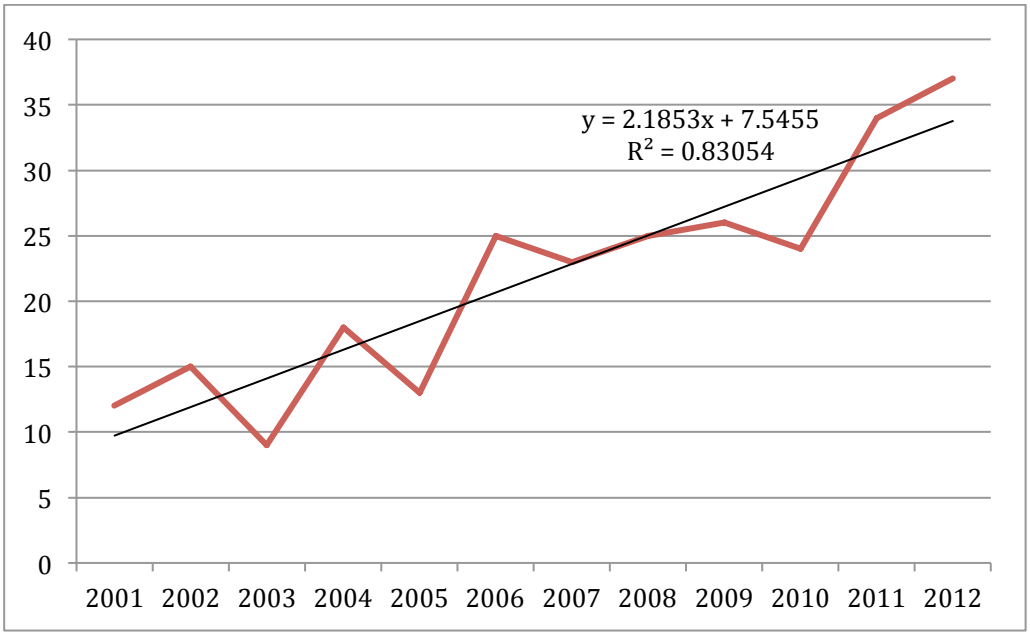


Figure 2.9 Number of LAA pre-hospital thoracotomies carried out 1991-2012



Chapter 2.5 How might mortality from TCA be improved in the future?

2.5.1 THE CHALLENGE OF HYPOVOLAEMIC CARDIAC ARREST

The previous chapters have questioned the concept that resuscitation of patients in cardiac arrest associated with trauma is futile. Several subgroups have been identified amongst whom appropriate resuscitation interventions might yield survivors. However, in identifying these sub-groups, I have possibly redefined the 'futile' group. The patients who sustain cardiac arrest on scene from hypovolaemia very rarely survive. This is most likely to be due to the high rate of bleeding (usually non-compressible) necessary to cause cardiac arrest before arrival in hospital. Patients arriving shortly before or after cardiac arrest in an emergency department may have an increased chance of survival with the immediate availability of blood products and surgical intervention. What can be done to rectify this situation? It is unlikely that one intervention is the solution to this difficult problem. Timely haemorrhage control, replacement of blood and prevention of organ damage or failure are all components that need to be urgently addressed in these patients. Can a comprehensive trauma system that provides key interventions at scene, during transfer to hospital and after arrival in hospital prevent or deliver survivors from hypovolaemic cardiac arrest? A recent publication from the UK military claims that the trauma system in place in Afghanistan delivers unexpected survivors and of 78 patients with traumatic cardiac arrest 18 (24%) survived (118). This survival rate appears to be exceptionally good. The patients are predominantly young and injuries were mostly due to improvised explosive devices or gunshot wounds. The authors do

not claim that a single intervention is responsible for this success but instead emphasize the well practiced and aggressive approach to hypovolaemia at every stage in the acute phase of care – on scene, during evacuation, in the emergency department and in theatre and beyond. This approach and the encouraging results have led us to examine every aspect of the pre-hospital care given to hypovolaemic patients in our system in the hope that optimising existing care as well as the implementation of newer interventions may improve survival.

The last decade has seen a significant increase in publications on, and interest in, the management of trauma-related haemorrhage. Progress has been made at all levels - from a better understanding of haemorrhage at a basic science level through to changes in practical procedures performed on bleeding patients in the emergency department. Clinicians have seen the introduction of older concepts like hypotensive resuscitation (119) adopted into mainstream resuscitation practice (1) and are now considering how an improved understanding of acute traumatic coagulopathy (120) can guide practice. Damage control resuscitation and surgery, the early use of blood and blood products and practical haemorrhage control techniques with topical haemostatic agents and tourniquets have been rapidly moved forward in military trauma practice and in many civilian trauma services. Consensus on best civilian practice after interpretation of recent progress and data is not straightforward but has been attempted recently (121).

The philosophy of a physician-led trauma service influences the level of care provided. Few would disagree that patients who require immediate surgery for haemorrhage control should be transported to a hospital with appropriate

facilities without delay. Unfortunately this is not always possible and analysis of scene times reveals that in many systems a significant proportion of trauma victims spend the majority of the first hour after injury outside hospital (122,123). In geographically isolated areas and with patients who are trapped this time may be further extended. The development of regional trauma systems in some countries has potentially increased pre-hospital times with the introduction of ‘bypass to major trauma centre’ policies. Systems like ours recognize that care is often suboptimal prior to arrival in hospital and that time critical clinical problems may need to be addressed prior to arrival in hospital. Airway management is a controversial area, which illustrates this problem. In the USA, a review of available publications by the Eastern Association for the Surgery of Trauma (EAST) (124) noted that ‘seven studies indicate that 70% of patients in need of emergency tracheal intubation do not receive it until trauma centre arrival. This suggests that a large percentage of critically injured patients have ‘a delay in optimal care’. In one study of trauma patients who required intubation after arrival in hospital, half were for ‘immediate indications’ such as airway obstruction, severe hypoxaemia or cardiac arrest, which were already present on arrival in the emergency department (125). UK experience demonstrates similar problems (17). In a proportion of trauma patients, major haemorrhage is, like airway compromise, a time critical clinical problem that also requires rapid attention after injury to avoid preventable death.

The concept of ‘Critical Care without walls’ was applied by Hillman in 2002 to patients with critical illness who happened to be on wards outside a critical care area (126). He noted that the patient’s location rather than acute needs appeared to determine the level of care delivered. This model was used to

develop hospital medical emergency teams but it is a concept that we use in pre-hospital critical care – if a trauma patient has a condition which is life-threatening and can be effectively treated by the attending team it should be dealt with immediately. Another ‘critical care’ concept that influences our practice is the ‘care bundle’. This approach combines interventions (127) in the belief that the sum of carefully applied interventions is likely to be more effective than individual components. The number of interventions is relatively small and ideally evidence based. The LAA ‘pre-hospital haemorrhage care bundle’ attempts to combine all interventions of proven benefit to achieve early haemorrhage control and deliver them to appropriate patients. The rigorous measurement of compliance is key to this approach. The parallel processes of quality assurance (or clinical governance) and innovation are key to trauma systems. Ensuring that the basics are done properly and auditing practice of established (often basic) methods of haemorrhage control is as important as the development and implementation of new approaches. This article will use several examples of haemorrhage control techniques to examine how established and innovative practice have been integrated into routine care, achieving good scene times, appropriate triage and appropriate good practice standards.

The importance of short scene times in trauma patients particularly those with shock has been emphasized in many publications and guidelines. However scene times may be misleading. Transport of a patient with immediate time critical but treatable pathology may lead to poor outcomes (84). Time from injury to definitive treatment e.g. laparotomy or craniotomy in the minority of patients who need immediate surgery, is a more important time interval. Direct transfer

to a trauma centre may be more likely to achieve this. Where critical interventions have been carried out before arrival in hospital the time in the emergency department may also be reduced. ‘Direct to CT’ policies where the patient is taken to CT before arrival in the emergency department are being explored in several UK centres in selected patients accompanied by a pre-hospital physician. It has recently been established that CT scanning can even be achieved outside hospital (128). In the UK, pre-hospital times in non-trapped trauma patients attended by ambulance crews have been reported to be in the region of 40 - 45 minutes. LAA aims to achieve scene times of less than 10 minutes for awake patients with penetrating trauma and 25 - 35 minutes for patients with blunt trauma who require on scene interventions. In 2011 mean scene times for 346 awake trauma patients were 11.4 minutes for penetrating trauma and 36 minutes for patients with blunt trauma and interventions (e.g. pre-hospital anaesthesia, procedural sedation, chest decompression) carried out on scene. Triage to a centre capable of treating the identified injuries is important. This has been formalized in the UK with the development of Major Trauma Centres and trauma decision triage tools. In common with the USA’s experience (129), moderate overtriage is expected to avoid any undertriage. Undertriage is very uncommon in our system (less than 1%) and is always carefully examined at quality assurance meetings. A key national guideline related to haemorrhage was published in 2004 in the UK by the National institute of Clinical Excellence which recommended 250 ml crystalloid boluses in patients suspected of bleeding who had absent peripheral pulses. Our service was compliant with this recommendation before it was published.

2.5.2 GENERAL MANAGEMENT OF BLEEDING

Consensus on general approaches to bleeding for in-hospital trauma patients has been reached with some difficulty (121). Published military experience has been highly influential in changing practice but the exact relevance of military experience to civilian trauma practice has been questioned in several areas (121). At LAA, we have carefully evaluated the available evidence and implemented techniques on the basis of potential benefit and lack of harm.

Tranexamic Acid administration

An example of an established in-hospital treatment that has been recently introduced into routine pre-hospital practice is the administration of the antifibrinolytic agent tranexamic acid. The large multicentre randomized controlled CRASH 2 trial published in 2010 recruited more than 20,000 patients (21). The study suggested a mortality benefit in trauma patients when given in the first four hours after trauma but administration within one hour of injury was most beneficial. The patient group targeted for this intervention, are those suspected of major haemorrhage. Optimal outcome for this group of patients requires minimal transfer time to a major trauma centre and no delay for additional interventions on scene. The compromise between these two competing principles for us was to administer the drug during transport. The first 60 patients who received the drug had completed administration by a mean 58 minutes post injury.

Patient handling

A more established concept in trauma management is that of gentle patient handling to prevent clot dislodgement – particularly in patients with a fractured pelvis (1). Careful examination of pre-hospital standard ambulance procedures

in our system some years ago led to a change of practice to achieve best practice. Before the change, injured patients were log rolled onto a long spinal board on scene and then log rolled again on arrival at hospital to remove the board. Simple analysis of rotational movement with potential for clot dislodgement revealed that a patient found injured with a fractured pelvis in the semi prone position would have 510^{o} of rotation before being supine on a hospital trolley. Changing practice to reduce movement involved insertion of the two halves of an orthopaedic scoop stretcher on scene and removal with only careful counter-traction in the emergency department. This resulted in a reduction of rotational movement from 510^{o} to 170^{o} in the example described above. Similar benefits may be achieved with other bleeding sites e.g. multiple rib fractures. Attention to smaller sites of blood loss e.g. basic suturing of scalp lacerations may help prevent cumulative blood loss. Constant review of current practices may deliver similar benefits which translate to deliver recent innovation.

2.5.3 BLEEDING FROM SPECIFIC ANATOMICAL SITES

Techniques have been developed and adapted to treat haemorrhage at specific anatomical sites. Some are techniques routinely used in EMS systems around the world – applied strictly according to standard operating procedures and reviewed regularly. Other techniques have been developed to deal with our specific patient case mix and available provider skill set.

Pelvic fractures and maxillofacial haemorrhage

Severe haemorrhage and death from severe pelvic fractures is seen regularly in our blunt trauma population particularly among cyclists and motorcyclists. Rapid application of pelvic splints has been standard practice for more than 15 years.

Commercially available splints have replaced the original elasticated splints. Maxillofacial haemorrhage is often encountered in conjunction with head injury. A combination of techniques is used to immobilize and splint fractures and restore normal anatomy. Patients are usually intubated. The tracheal tube provides a degree of splinting as well as airway protection. The facial skeleton is splinted with a well fitted rigid cervical collar (mandible). Two bite blocks are applied between the molars (mandible / maxilla) and two nasal epistats (Medtronic, Minneapolis. USA) are inserted into the nasal cavities with one or both inflatable balloons inflated. The maxilla may be gently realigned where necessary when the bite blocks are inserted.

External haemorrhage control

Military practice has led to a resurgence of interest in tourniquet application for limb haemorrhage (130) and the use of topically applied haemostatic agents in addition to efficient compression dressings. We introduced the Combat Application Tourniquet (CAT™, Rock Hill, Ca USA) and Celox™ (MED Trade Products, Crewe, UK) gauze dressings into practice 3 years ago and have recorded 23 tourniquet and 11 Celox™ gauze uses in the same period. Clinical case review does not confirm any obvious benefit in terms of visible haemorrhage reduction. This may be because of the later application and different mechanisms of injury in civilian practice compared with military practice. Non compressible haemorrhage in junctional zones can also be compressed with insertion and inflation of the balloon of a Foley catheter.

Pre-hospital thoracotomy and treatment of expanding intracranial hematoma.

Relatively small volumes of blood loss into anatomically restricted spaces close to vital organs can rapidly cause death. Pericardial tamponade after penetrating trauma and expanding intracranial hematoma are key examples.

The use and results of immediate thoracotomy for cardiac arrest associated with penetrating trauma has been discussed in detail in previous chapters.

Expanding intracranial hematoma is a time critical emergency. Control of ventilation and use of hyperosmolar solutions with immediate transfer to a neurosurgical centre has been the mainstay of pre-hospital management in our system. The evacuation of intracranial hematoma outside neurosurgical centres is virtually unheard of in the UK. It has been noted that evacuation of hematomas by non-neurosurgeons in geographically isolated areas may produce survivors while similar patients transferred to trauma centres may miss the opportunity for early evacuation (131). Re-examination of this intervention to provide evacuation in patients with fixed dilated pupil(s) before arrival in a neurosurgical centre may be appropriate. The availability of perforator drill bits with a clutch mechanism may make the procedure much safer. In our system patients with a head injury and reduced level of consciousness can now have point of care testing for INR if it is suspected that they are taking Warfarin. Using the INR result and a dosing nomogram, prothrombin complex concentrate is administered on route to hospital in an attempt to reverse anticoagulation as early as possible and limit the size of the intracranial hematoma.

2.5.4 EARLY ACCESS TO BLOOD AND BLOOD PRODUCTS

Massive transfusion policies for patients identified to have severe bleeding are mandatory in UK major trauma centres (4). A ‘code red’ policy has been established in our centre and others to activate a pre-determined blood and

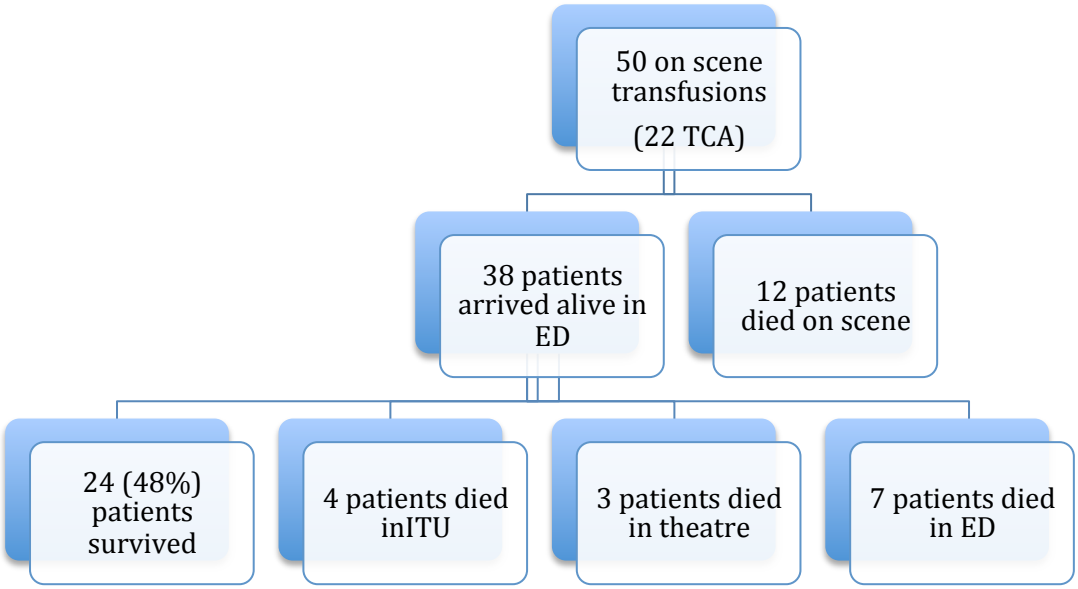
blood product package for bleeding trauma patients. The policy is activated by the hospital trauma team leader and, in an attempt to have blood and blood products available on arrival at the emergency department the policy can be activated from scene by the attending pre-hospital doctor. The policy is activated on the basis of suspected or confirmed active haemorrhage and a recorded systolic blood pressure of <90 mmHg, failure to respond to a crystalloid fluid bolus (usually administered by the ambulance service) is also taken into consideration. These simple activation criteria have been monitored to establish whether they correctly identify patients with bleeding and a transfusion requirement. Initial data demonstrated that in the first 30 months of operation approximately 3.6% of trauma missions generated a ‘code red’ request. Analysis of available data on 92 ‘code red’ patients received in our hospital demonstrated that the patients had a high mortality rate (31.5%) and were severely injured (Median Injury Severity Score (ISS) 27). Blood was always available on patient arrival. Records of blood product use revealed that overall a mean of 11.6 units of PRBC and 7.2 units of FFP were administered. Survivors received less blood products than those that died. These preliminary data suggest that simple physiological criteria identify severely injured patients who require transfusion. The criteria are necessarily very basic and adopted to make pre-hospital decision making straightforward. It is our intention to compare the sensitivity and specificity of the pre-hospital criteria to established in-hospital criteria (132).

In April 2012 our service became the first UK civilian pre-hospital service to routinely carry blood to the scene. In conjunction with our blood transfusion service a reliable system has been developed where four units of O negative

packed red cells are carried in lightweight refrigerated containers with temperature monitors. The blood is returned to the blood bank if unused after 24 hours.

In the first six months of operation 50 blood transfusions were given on scene in approximately 4% of trauma missions. The mean age was 35 years and 40 (80%) were male. The mean number of units transfused on scene was 2.8. One unit of blood was wasted and 100% traceability was achieved. A pre-transfusion sample is taken and delivered to the receiving emergency department. Consultant telephone authorization is obtained before commencement of transfusion. Pre-hospital fresh frozen plasma has not been added to the blood because of the logistical difficulties and cost. The current change of practice is therefore the use of packed cells in place of 250ml boluses of crystalloid rather than extension of full emergency department transfusion protocols into the pre-hospital phase of care. We are keen to establish whether this change of practice influences the almost 100% mortality rate of traumatic cardiac arrest secondary to hypovolaemia previously reported in our system (76). We are carefully looking at developments in dried fresh frozen plasma, point of care ROTEM testing and fibrinogen administration to consider possible applications in our service. Safety considerations make the use of fresh whole blood in pre-hospital civilian UK practice highly unlikely.

Figure 2.10 First 50 on -scene blood transfusions



ED = Emergency Department, TCA = Traumatic Cardiac Arrest ITU= Intensive Care Unit

2.5.5 FUTURE INTERVENTIONS FOR THE TREATMENT OF HYPOVOLAEMIC CARDIAC ARREST PATIENTS

The examples discussed in this article demonstrate a wide range of techniques applied to traumatic haemorrhage in general and to haemorrhage at specific anatomical sites. We believe that quality assurance of existing basic and more advanced techniques is as important as the use of new or innovative techniques. New point of care testing and diagnostic methods are improving and are increasingly available on scene. Introduction of these technologies must provide the possibility of useful change in management to justify any additional delay on scene. Many of the techniques described above are aimed at reduction of haemorrhage and the prevention of hypovolaemic arrest. They

are likely to be less useful in established or near hypovolaemic cardiac arrest. Technological advances that may be applied to on-scene haemorrhage control in the near future include emergency preservation resuscitation (EPR) (133), resuscitative endovascular balloon occlusion of the aorta (REBOA] (134,135) and extracorporeal cardiac life support (ECLS) (136).

EPR is a concept that has been developed by several research groups but particularly by Tisherman et al from Pittsburgh USA. A long series of animal studies in rats and dogs have been used to establish the viability of rapid profound hypothermia in cardiac arrest. This was an extension of the established benefits of mild hypothermia in cardiac arrest (137) and extension to 'profound' hypothermia (10^{o}C) and 'ultraprofound hypothermia' (0-5^{o}C). As development progressed, it was noted that for the technique to be viable 'it would have to be commenced within the critical first five minutes of cardiac arrest' (138). The concept is that shortly after cardiac arrest cold saline is infused rapidly into the descending aorta to achieve hypothermia. The surgical lesion is then repaired and the patient then rewarmed on cardiopulmonary bypass. The time of hypothermic arrest in dogs was initially 60 minutes but then extended successfully to 120 minutes (139). It was then applied to experimental models which included hypovolaemic cardiac arrest and surgical operations (thoracotomy and laparotomy) during the no-flow period (140). A study that aims to recruit 20 victims of penetrating trauma in cardiac arrest in the emergency department and subjecting them to resuscitative thoracotomy, EPR, surgical repair and rewarming on cardiopulmonary bypass has received ethical approval and should be recruiting in 2013/14 (Emergency preservation and resuscitation (EPR) for cardiac arrest from trauma (EPR-CAT) Clinical trials.gov

trial identifier NCT 01042015). Endpoints are feasibility of the technique in humans, survival, neurological outcome and organ dysfunction. Patients who are in asystole or have been in cardiac arrest are excluded. The results of this study are eagerly awaited. If the technique works this will define a small group of patients identified in our system (hypovolaemic with cardiac arrest on scene) who currently have almost 100% mortality who may benefit from a pre-hospital intervention and then, after rapid transfer to hospital, surgical repair and rewarming on bypass in hospital. The technical challenges of patient selection and induction of profound hypothermia on scene are considerable but pump technology has improved considerably and the lead investigator on the US program has suggested to the author that this may well be possible (personal communication).

Resuscitative endovascular balloon occlusion of the aorta (REBOA) is not a new technique. It was first described in 1954 in victims of the Korean war. It is an endovascular method of external aortic occlusion traditionally performed at resuscitative thoracotomy and performed as an adjunct to internal cardiac massage when pre-hospital thoracotomy is performed in our service. The US military have performed a considerable number of large animal studies with a view to introducing the technique into military and civilian resuscitation practice. In pig models it has been found to be effective in models of pelvic haemorrhage where distal aortic occlusion is performed (134). Balloon occlusion has also been demonstrated to produce less physiological insult with the same central pressures as thoracotomy with aortic occlusion (141). The reperfusion insult with REBOA has been demonstrated to be significant but manageable even after 90 minutes of haemorrhagic shock and REBOA in pig models (142). High

placement of the aortic balloon for abdominal bleeding with compromise of renal and mesenteric vessels is likely to be problematic after short occlusion intervals but the role of low occlusion for pelvic haemorrhage looks promising. A centre in France have published a series of REBOA cases in thirteen patients with massive pelvic bleeding (143). All patients had successful balloon placement and six survived. The procedure is set up and an evaluation ready to proceed in the emergency department of our major trauma centre. In parallel with this a feasibility study in a pig model performed in a pre-hospital environment with ultrasound guided distal balloon placement is currently being set up by the author and another European research group. We anticipate rapid translation to our pre-hospital service targeting peri-arrest patients with suspected severe pelvic haemorrhage. This may be an intervention where temporary haemorrhage control and blood administration may bridge the interval to definitive treatment in hospital.

These techniques may well provide exciting opportunities to produce survivors from a group of trauma patients who, with current conventional treatments have 100% mortality.

Chapter 6: Standardisation of current best practice

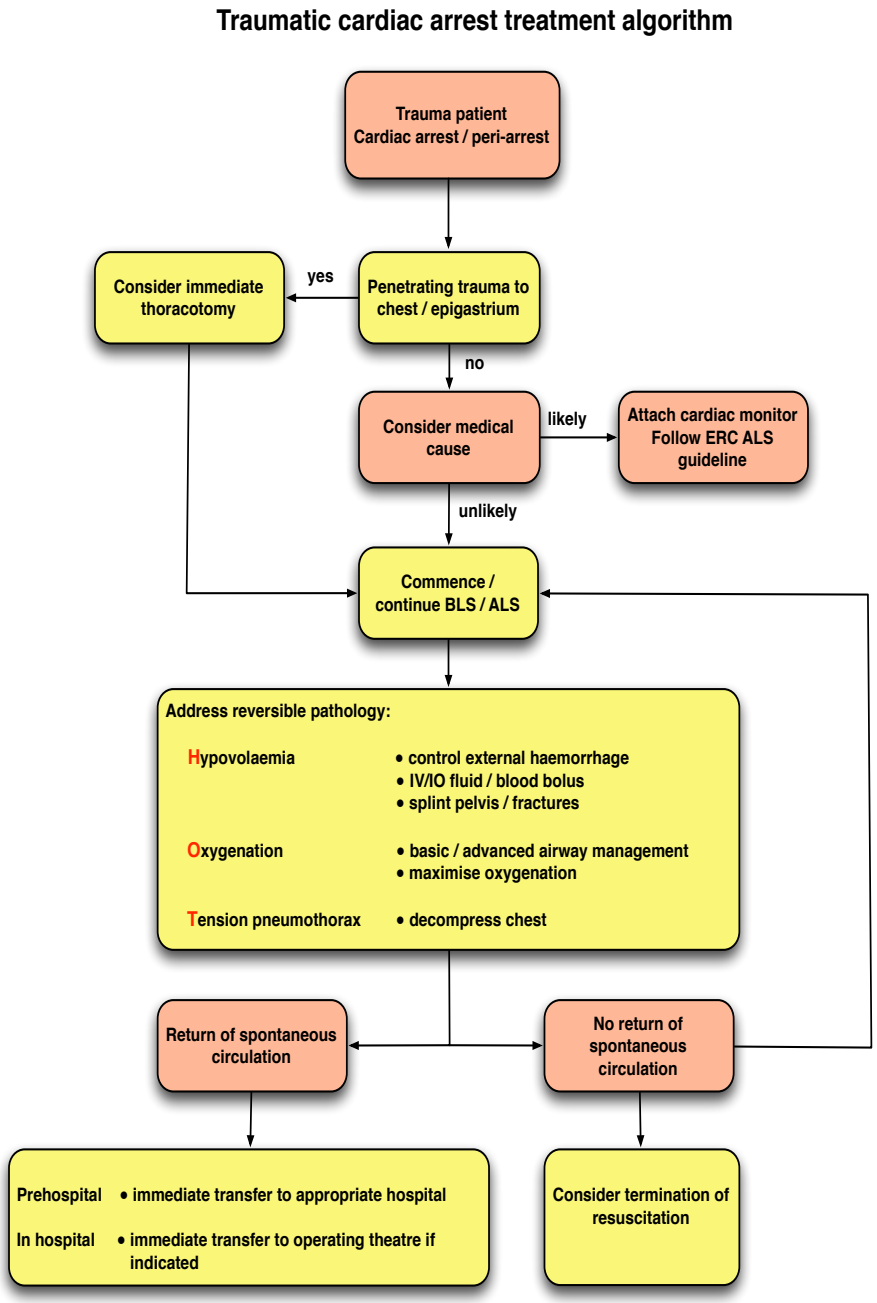
2.6.1 INTRODUCTION

The previous chapter has considered the challenge of hypovolaemic cardiac arrest and the potential use of existing and new techniques to reduce mortality. Meanwhile, despite the high mortality from traumatic cardiac arrest, survival with good neurological outcome has been regularly reported. Despite a weak evidence base, rapid and effective intervention to address potential reversible causes of TCA is needed if the victim is to survive. Where a number of interventions are required in a timely manner in medical cardiac arrest, resuscitation algorithms have been long established. Current ILCOR guidelines, however, do not contain a standard algorithm for management of traumatic cardiac arrest. On the basis of the available evidence including that described in the other chapters in this section, I, with others, brought together the available evidence, developed and recently published a simple algorithm to manage the major trauma patient in actual or imminent cardiac arrest (144).

The algorithm concentrates on reversible pathologies. Analysis of the civilian TCA survivors in our series has indicated that most survivors had pathology which could be relatively easily reversed once access to the patient was achieved (76).These included reversal of hypoxaemia or hypoventilation, relief of tension pneumothorax and immediate implementation of standard advanced life support in the group of patients who have sustained a ‘medical cardiac arrest’ as part of or cause of their ‘trauma episode’. In these cases outcome is likely to depend on the well-established prognostic indicators of early CPR and defibrillation (28) as well as the nature and severity of any injuries. The only well-established operative intervention that can result in neurologically good

outcome in TCA, is immediate thoracotomy for penetrating chest trauma. This is likely to be particularly successful where cardiac arrest is due to cardiac tamponade and a simple cardiac wound (88). In most emergency medical service (EMS) systems thoracotomy is only conducted in the emergency department. EMS crews must move at-risk patients quickly to where thoracotomy is available. As I have demonstrated - where physician-based pre-hospital care is available, resuscitative thoracotomy can be performed successfully on scene (145,146). Survival appears much more likely if the procedure is carried out at the time of cardiac arrest and delay is reported to result in almost certain mortality. All of the potentially reversible pathologies were addressed in the 2010 ILCOR guidelines (28). However, because a limited number of interventions need to be performed in a very short time period to address reversible pathology, the management of TCA is suitable for a treatment algorithm. The algorithm below takes account of the published data on TCA and describes a simple treatment algorithm to address key reversible pathologies. The algorithm does not differentiate between pre-hospital and in-hospital care. Where time critical reversible pathology exists it requires the same treatment regardless of where the patient is at the time of diagnosis. Some pre-hospital services may not be able to deliver all required interventions on scene but if this is the case the algorithm can be used to assist in the identification of priorities and consider how urgent transfer to hospital can address any remaining issues.

Figure 2.11 Treatment algorithm for traumatic cardiac arrest



2.6.2 EXPLANATION OF ALGORITHM

The algorithm aims to rapidly identify and correct reversible causes of TCA.

Transport of TCA patients from the pre-hospital to hospital setting with on-going

cardiopulmonary resuscitation is usually futile and key interventions need to be performed as soon as possible, usually on-scene. Patients arriving at a hospital in traumatic peri- or cardiac arrest need reversible causes immediately excluded and managed prior to transfer for diagnostic imaging or surgical intervention. The treatment priorities in this algorithm have been applied by a physician-led pre-hospital trauma service to over a thousand TCA's attended over an eighteen year period. Published results demonstrate that adherence to these principles can result in improved survival rates from TCA (76,146).

Diagnosis of traumatic cardiac arrest

The diagnosis of TCA is based on rapid clinical assessment (28). Agonal, abnormal or absent spontaneous respiration and absence of a central pulse over a 10-second period should immediately prompt entry into the algorithm if there is a possibility that the cardiac arrest could be traumatic in origin. Recognition of the peri- or cardiac arrest state should take less than 10 seconds and not be delayed to initiate monitoring. In cases where death can be categorically confirmed (decapitation, rigor mortis etc.) resuscitation should not be commenced. Where available, rapid assessment with focused ultrasound may be useful in the diagnosis and management of the peri-arrest patient but should not delay urgent intervention (147).

Trauma resulting in a peri –arrest patient

Victims of major trauma may present in a peri-arrest state. Cardiovascular instability, including bradycardia, profound hypotension or rapidly falling blood pressure, loss of peripheral pulses, together with a deteriorating conscious level should immediately alert the emergency care provider of imminent cardiac arrest. Rapid, targeted interventions may prevent cardiac arrest. Peri-arrest

patients should immediately be entered into the algorithm. In cases where the patient is still self-ventilating, early drug-assisted tracheal intubation may be required.

Basic / Advanced Life Support

Patients in TCA should have basic and, if available, advanced life support commenced immediately. All emergency care providers should be familiar with recognition of cardiac arrest and initiation of basic life support. Depending on the cause of traumatic cardiac arrest chest compressions may provide some blood flow during cardiac arrest and should be continued whilst the history and mechanism of injury is established. In profound hypovolaemia, chest compressions are likely to be ineffective due to poor cardiac filling and external compression of an empty heart (148). Haemorrhage control and volume replacement should occur immediately. Immediate diagnosis of hypovolaemia may be difficult and, if in doubt, chest compressions should be continued. The patients with the greatest chance of survival are normovolaemic and cardiac compressions may be at least partially effective while reversible pathology is addressed simultaneously. Standard BLS / ALS without urgent attention to reversible pathology is unacceptable and unlikely to result in return of spontaneous circulation (ROSC) (unless the cardiac arrest was of ‘medical origin’). If cardiac compressions have been started they should be continued until interventions addressing reversible pathology are commenced.

Penetrating trauma

Patients with penetrating wounds to the chest, epigastrium or between the scapulae resulting in cardiac arrest usually have cardiac tamponade and obstructive shock or have an empty heart as a result of hypovolaemia (50). For

the patient to have any chance of survival, immediate surgical intervention is required. Surgical intervention, in the form of resuscitative thoracotomy, should be performed immediately in any patient with penetrating trauma to the chest or epigastrium in peri- or established cardiac arrest. Timing of this intervention is critical. The chances of survival after emergency thoracotomy fall rapidly after loss of vital signs (28). In the emergency department it has been demonstrated that if blunt trauma patients have had more than five minutes of CPR or penetrating trauma patients have had more than 15 minutes resuscitative thoracotomy is likely to be futile (149). In contrast in the penetrating trauma patient where loss of vital signs has occurred in the presence of a thoracotomy provider or in the 10 minute period before, the procedure has been effective and should be carried out without any delay for less effective interventions (146). Pre-hospital resuscitative thoracotomy should be performed if trained personnel are on-scene because patients who lose vital signs on scene rarely survive even if emergency thoracotomy is performed in the emergency department (145,146). As discussed in chapters 2.2 and 2.3 pre-hospital thoracotomy has been associated with a significant survival rate in patients with cardiac tamponade (76,146) but needs to be performed in systems with clear governance processes in place (100). Patients presenting to the emergency department in cardiac arrest or peri-arrest should be considered for immediate resuscitative thoracotomy on arrival (150). Any delay in undertaking resuscitative thoracotomy when it is indicated will decrease the patient's chance of survival. Resuscitative thoracotomy undertaken in the pre-hospital or emergency department setting does not aim to address all the possible lesions that can result in cardiac arrest following penetrating chest trauma. An

immediate cardiothoracic or trauma surgical response will only be available in a proportion of cases. Resuscitative thoracotomies performed by non-specialist surgeons or non-surgeons can only be expected to address a limited number of pathologies. Pre-hospital resuscitative thoracotomy aims to treat simple cardiac wounds, resulting in pericardial tamponade (91). In the majority of traumatic pericardial tamponade cases, the pericardial sac contains considerable volumes of clotted blood and there is no place for needle pericardiocentesis in treatment (145). Therefore thoracotomy and formal pericardotomy are needed. Where release of cardiac tamponade does not result in ROSC patients may benefit from high quality, internal cardiac massage to achieve return of spontaneous circulation. Resuscitative thoracotomy in TCA from blunt trauma is much less likely to be successful and injuries present are more likely to be complex and less amenable to treatment by non-surgeons (19,151). The availability of blood for immediate transfusion may improve outcome in these patients but further research is required in this area.

Traumatic versus medical cardiac arrest

Establishing the origin of cardiac arrest may not be straightforward. A primary medical arrest may occur prior to a patient suffering a traumatic insult. Such patients may initially appear to have suffered a TCA but have suffered minimal, if any, injuries. Primary medical cardiac arrests resulting in falls from height or road traffic collisions are examples which may typically result in emergency care providers suspecting cardiac arrest of traumatic origin. Close attention should be paid to witness history and an accurate scene assessment made to establish the course of events and mechanism of injury. If there is a possibility that the patient has suffered a primary medical cardiac arrest, chest compressions

should be continued, a defibrillator requested immediately and ILCOR resuscitation algorithms followed. Where medical cardiac arrest is not suspected cardiac monitoring should still be applied early in the resuscitation attempt. Standard defibrillation should be carried out if a rhythm compatible with defibrillation is discovered in the traumatic cardiac arrest patient.

'HOT' – hypovolaemia, oxygenation and tension pneumothorax

Victims of TCA may have one or more injuries resulting in severe hypovolaemia, critical hypoxaemia or tension pneumothorax, either in isolation or concurrently. Active management of these conditions needs to be addressed simultaneously by the pre-hospital or hospital trauma team.

Hypovolaemia

Active external haemorrhage should be controlled with the application of immediate direct pressure to actively bleeding wounds. After bleeding from isolated bleeding wounds has been effectively controlled volume re-expansion should follow. Recent military experience has focused on aggressive management of compressible haemorrhage with the use of pressure dressings, topical haemostatic agents and tourniquets (130). Control of obvious haemorrhage can only be beneficial although clear evidence of survival benefit is scarce. Routine translation of tourniquet use to civilian practice is even less likely to demonstrate benefit since, in contrast to military mechanisms of injury, blunt trauma rarely results in traumatic amputation and in civilian practice a tourniquet is likely to be applied much later after injury than point of wounding application by a wounded soldier or his immediately available colleagues. The availability and use of tourniquets in civilian trauma practice may be increasing on the basis of recent military experience and civilian major incidents (152,153)

and tourniquet use is incorporated into the American College of Surgeons Advanced Trauma Life Support course (154).

After initial haemorrhage control and other critical interventions have been achieved fractures of the pelvis and long bones should be splinted. Haemorrhage into pelvic and long bone fractures can be significant. Open fractures with haemorrhage need immediate attention and should be dealt with as ‘active external haemorrhage’. Closed fractures should be splinted to prevent on-going haemorrhage after initial urgent interventions. If there is a suspicion of a pelvic fracture a pelvic binder should be applied taking care to minimise patient movement during application and the pelvis reduced to anatomical position. Long bone fractures should be reduced to anatomical position and splints applied.

A patient in TCA as a result of hypovolaemia is unlikely to achieve return of spontaneous circulation unless haemorrhage control is performed in combination with intravascular volume replacement.

Where patients are peri-arrest or where bleeding has been addressed early volume replacement with blood products is required. Administration of blood is likely to be more beneficial than crystalloid or colloid infusion in this patient group (155). Where indicated, blood and blood products should be transfused immediately on arrival at the emergency department or in the pre-hospital setting if available. Pre-hospital activation of major transfusion protocols should diminish the time required for the patient to receive blood products (152). In hospital, blood products should be immediately available and massive transfusion protocols initiated.

Oxygenation

Airway management and optimising oxygenation are important. Hypoxia secondary to complete or partial airway obstruction, traumatic asphyxia and ventilatory failure may be the cause of cardiac arrest and can be straightforward to treat. Major trauma victims are likely to have a high oxygen requirement. Initial attention should be paid to high quality, basic airway management with cervical spine control, using airway adjuncts if required. Attention to basic airway management is paramount to the unconscious trauma patient who is at risk of airway compromise. Definitive airway management, in the form of a cuffed tracheal tube, should be achieved as early as possible. Advanced airway management should be achieved within a safe operating system and several guidelines are available
(156-158). Ventilation through a tracheal tube will ensure high concentration oxygen delivery, protect against airway soiling and provide positive pressure ventilation. Intubation without drug assistance is likely only to be possible in patients with a very high mortality rate (19,20). A small proportion of trauma patients who are not in cardiac arrest require drug assisted intubation to facilitate tracheal intubation and adequate ventilation (159).

Tension pneumothorax

Tension pneumothorax should be actively excluded in TCA. Needle chest decompression is rapid and within the skill set of most ambulance personnel but is of limited value in TCA (160,161). A proportion of patients will have soft tissue greater than the length of a standard 14-gauge cannula when placed in the second intercostal space, in the mid-clavicular line, which may lead to ineffective chest decompression (162). Cannulae are also prone to kinking or blockage (163).

Tracheal intubation, positive pressure ventilation and formal chest decompression will effectively treat tension pneumothorax in patients with TCA. Simple thoracostomy (164,165) is easy to perform and used routinely in several pre-hospital physician services. This consists of the first stage of standard chest tube insertion - a simple incision and rapid dissection into the pleural space in the positive pressure ventilated patient (161,164-166). Chest tube insertion is carried out after the resuscitation phase. Tube thoracocentesis requires additional equipment, takes longer to perform and creates a closed system that has the potential to re-tension. Chest drain tubes may become blocked with lung or blood clots and have the potential to kink (167,168).

Post-ROSC care

If return of spontaneous circulation is achieved in the pre-hospital setting, rapid transport to an appropriate hospital is required. A pre-alert should be passed to the receiving hospital. Following in-hospital resuscitation from TCA hypovolaemic patients should be immediately transferred to an operating theatre or interventional radiology facility to control major haemorrhage. More stable patients may be considered for further diagnostic imaging. In patients with ROSC consideration should be given to local guidelines in place for management of trauma patients. Examples may include target blood pressures for patients with ongoing haemorrhage or the institution of mild hypothermia in patients with neurological injury. If ROSC is not achieved on-scene, consideration should be given to terminating the resuscitation attempt.

2.6.3 DISCUSSION

The use of algorithms in emergency medicine and pre-hospital care ensures standardised, rapid delivery of clinical interventions in a structured manner for

critically unwell patients. Resuscitation algorithms for medical cardiac arrest are well established and incorporated into regular training for both pre-hospital and hospital personnel. It is important that providers of emergency care appreciate that resuscitation from cardiac arrest is not always futile. Outside specialist centres, EMS personnel and hospital staff involved in emergency care are unlikely to be involved in trauma resuscitation on a regular basis. Having a standard algorithm should assist clinicians in the provision of rapid, effective, consistent treatment to victims of major trauma resulting in near or actual TCA. It also focuses care on the likely key reversible pathology. The absence of a treatment algorithm may delay treatment or result in resuscitation not being attempted (169).

A standard simple approach to traumatic cardiac arrest is feasible and addresses all key reversible pathology that needs to be addressed to maximise the chance of survival. Use of a treatment algorithm may rapidly and simultaneously address reversible causes of traumatic cardiac arrest and has the potential to save lives. The utility of this algorithm will need to be established and may need adjustment in the future. Initial response to it has been favourable.

Chapter 2.7 Conclusions – TCA

2.7.1 CONCLUSIONS

This section has examined several aspects of a very high mortality condition. The mortality rate is somewhat misleading particularly when considered in the pre-hospital phase of care because all patients with unsurvivable injuries will, by definition, suffer cardiac arrest. For this group only injury prevention measures are likely to improve survival. My systematic review combined with our large series analysing the characteristics of resuscitated survivors indicated that there are sub groups of patients with this condition that have reasonable chances of survival. Some may suggest that those with the best chance of survival – those with hangings, drowning, inhalational and traumatic asphyxia and those with 'medical' cardiac arrest precipitating their 'trauma' event are not really victims of TCA. However this type of patient will inevitably be attended by trauma services and need to have their reversible pathology addressed competently and quickly. Our data provide good evidence that existing TCA guidelines are flawed and that after aggressive resuscitation neurologically intact survivors exist who would not have been resuscitated had the guidelines been adhered to. This does demonstrate how much harder it is to produce guidelines on withholding resuscitation than it is on how to resuscitate. Any documented survivors throw the guidelines into question even when sensitivity and specificity of the published criteria are very high. The guidelines do state that the criteria should be taken in the context of local EMS provision and physician level intervention may lead to different interventions and outcomes to other levels of care. The examination of pre-hospital thoracotomy demonstrates several important points relevant to pre-hospital trauma care. Firstly many complex interventions are

possible in the pre-hospital phase of care and the challenge is demonstration of benefit. Benefit is arguably easier to demonstrate in very high (or 100%) mortality patient sub-groups. Basing clinical guidance on low-level evidence is unsatisfactory but pre-hospital thoracotomy is an interesting example where high-level evidence is unlikely to ever be presented. Allocation of a control group to ‘standard’ resuscitation with expected 100% mortality is highly unlikely to be ethical where the intervention is available. Our attempt to define the likely demand for pre-hospital thoracotomy by examining the rate of penetrating trauma in the UK population did demonstrate increasing rates of penetrating trauma but also demonstrated that even in the UK – where a national trauma database has been in operation for many years, accurate and comprehensive trauma data is difficult to obtain.

Redefinition of a group of patients where treatment of TCA appears futile – hypovolaemic TCA - is inevitable but comes at a time where limited evidence from high resource military trauma systems environment throws historical data into question. The improvement of trauma systems and on scene interventions such as blood administration combined with innovative interventions like REBOA and EPR may lead to neurologically intact survivors from hypovolaemic TCA where currently there are none. Production of treatment guidelines and algorithms in the absence of high level evidence is difficult but if this results in the interventions which are in general use being administered more efficiently by more confident practitioners it may result in improved care. It remains to be seen whether an algorithm approach using currently acceptable techniques, or the development of a care bundle approach using existing or new techniques or the implementation of new techniques will result in increased survival in the

sub-groups which already have survivors or even in the sub-groups which do not.

Section III: Pre-hospital Advanced Airway Management

Chapter 3.1 Controversies in advanced pre-hospital trauma airway management

3.1.1 BACKGROUND

Airway compromise has been identified as a preventable cause of poor outcome and death in trauma and cardiac arrest patients for many years (170,171). The influential American College of Surgeons Advanced Trauma Life Support Course (ATLS™) (1) has propagated the 'ABC' approach to trauma care which makes the management of airway compromise the highest priority. Since uncorrected airway compromise leads to potentially preventable death or hypoxic brain injury this concept is generally accepted. However the means by which effective airway management should be achieved before arrival in hospital is not straightforward and highly controversial. After arriving in a hospital, the intervention of tracheal intubation (TI) is usually provided by appropriately trained physicians. In most countries these physicians are trained anaesthetists or emergency physicians with anaesthesia training (172,173). The in-hospital environment allows skilled assistance, the use of equipment and administration of drugs to optimise the conditions for tracheal tube insertion and minimise associated physiological derangement and other adverse events (173). Unsuccessful or poorly conducted attempts at TI can be life threatening and may result in significant complications, such as oesophageal intubation (174), hypoxaemia (175), or post-induction cardiac arrest (176). Rapid sequence induction (RSI) is generally accepted as the technique of choice for securing the airway in seriously ill or injured patients

(125,173). RSI comprises three elements- sedation, analgesia and muscle relaxation- all of which are necessary for a safe and effective TI. The drugs used to perform TI produce a state of apnoea, can induce hypotension and increase the risk of regurgitation and aspiration of gastric contents. Using them requires a high level of competence and the ability to deal with any adverse effects. In hospital settings, this requirement usually presupposes the educational level of a specialised physician.

In the pre-hospital setting, the situation is somewhat different. The first Medline- or Embase-indexed reports on pre-hospital ETI were published in the mid-to-late1960s (177-179). In the last ten years the value of pre-hospital ETI has been seriously questioned (96,180-182). Despite many published studies, the benefits of this practice in different patient groups, the skill levels required by the providers, the effect of different techniques and the alternatives to intubation are less clear now than ever before. The majority of the published papers are based on retrospective database methodologies and are considered to be low-quality evidence (183). Despite the publication of guidelines from Europe and the US that recognise the need for appropriately conducted pre-hospital RSI (156,158,184) in a limited number of patients**,** the practice is still widely variable between and within countries. In many European countries in which specially trained physicians have participated in pre-hospital EMS services since the late 1950s, RSI is a core component of pre-hospital advanced life support (185-187). In contrast, some pre-hospital EMS systems in developed countries base their advanced life support entirely on paramedics and/or nurses, and their ETI protocols and procedures depend far less on drug administration (188-190). A

recent systematic review extracted the Utstein airway template variables from studies reporting on pre-hospital ETI (159). The majority of the included studies (59.8%) were from North American EMS systems. Of these, 46 (78%) described services in which non-physicians conducted ETI. In contrast, physicians performed the pre-hospital ETIs in 13 (87%) of the 15 non-North American EMS systems. Of the 47 non-physician-manned systems, 25 (53%) performed drug-assisted ETI. The considerable heterogeneity of published studies makes it extremely difficult to generalise findings. The heterogeneity may stem from a number of areas. The professional group from which the providers come are usually documented but there are considerable differences between training and skill levels within professional groups. The term ‘paramedic’ can describe a very different provider in different EMS systems. The term ‘physician’ is even more ill defined. In some countries the term relates to a senior doctor with extensive experience and, in many European systems is often a consultant anaesthetist. In other systems the physician might be relatively junior trainee or a general practitioner with few advanced airway management skills. Case mix also varies in different studies. It is often difficult to separate trauma and non-trauma patients, cardiac arrest and non-cardiac arrest, adults and children. The use of drugs is also pivotal to intubation success but in a review of pre-hospital airway management in 2003 (124) which involved 263 publications and 9534 patients it was unclear in 21 studies (involving 2887 patients) whether or not drugs had been administered to facilitate intubation. Similarly a Cochrane review on the value of pre-hospital tracheal intubation (191) failed to separate paramedic and physician intubation or drug assisted intubation and intubation without drugs or medical and trauma patients.

In the UK paramedics have the full range of basic airway management skills (oxygen administration, chin lift / jaw thrust, bag-valve-mask ventilation, nasal / oral airway). In addition intubation without drugs has been carried out for more than twenty years. The benefits of intubation without drugs have not been demonstrated. One study did demonstrate benefit (192) but the same authors have subsequently published data which take an opposite viewpoint (193). In 2001 I published a large series of trauma patients who were intubated without drugs in London (19). Mortality was almost 100%, which suggested that the group of trauma patients who could be successfully intubated by paramedics were either in cardiac arrest, peri-arrest or severely injured. Other publications have supported the view that this intervention does not confer any benefit and also that success rates are relatively low - between 49 and 63%without drugs (194-196). As a result of this and recognition that the development of supraglottic airway devices has provided a less invasive but more effective option, the Joint Royal College Ambulance Liaison Committee in the UK made recommendations in 2008 that tracheal intubation should not be mandatory training for UK paramedics (197).

Paramedics in the UK do not carry out RSI although there are advocates for this development. Two studies in this area have drawn particular attention. In 2003 Davis et al published a prospective study of 209 patients who were unconscious and could not be intubated without drugs (198). They were intubated with midazolam and suxamethonium. Mortality and neurological outcome were then compared with 627 historical controls. Outcome in the RSI group were significantly worse. After sub-group analysis it was suggested that this might have been due to poor training or poor technique resulting in inappropriate

ventilation or hypoxaemia. A more recent study was unusual in that a randomised controlled study was achieved in unconsented critically unwell patients (199). Three hundred and ten patients with head injury were randomised to paramedic RSI or transport to hospital for RSI in the emergency department. Although no survival benefit was demonstrated in the pre-hospital RSI group there was an improvement in functional neurological outcome. However there were a significant number of reported unexpected cardiac arrests after induction in the RSI group which is of concern. There are other studies that record very high rates of complication after paramedic RSI. A study of 203 trauma patients received in an emergency department in Florida after paramedic RSI reported that 31% had failed intubation. Eighteen per cent could not be intubated after administration of suxamethonium and 12% had unrecognised oesophageal intubation on arrival (200).

On the basis of the available literature it is unclear whether reported sub-optimal results are due to the fact that the intervention of RSI is performed or because it is being performed badly.

In the second section of this thesis I have examined the conduct of airway management in one EMS system in detail and also attempted to address two questions of more general significance. The first study was designed to answer the question ‘Is there a demand for advanced airway management in trauma patients beyond that currently provided by the ambulance service?’ Data were collected prospectively on consecutive trauma patients on scene to assess airway compromise after paramedic attendance. Complications of paramedic and physician airway management were also recorded. Although intubation success rates are only one quality indicator of airway management they are

usually one that is recorded. Intubation failure after the administration of muscle relaxants is of particular concern.

My second study was a comprehensive metaanalysis of paramedic and physician intubation success rates that was carried out with an overseas colleague and a statistician. This study revealed a surprising lack of published data relating to pre-hospital physician RSI.

My third study examined intubation success rates in my own service. The success of rescue techniques and the differences in success rates between different physician operator specialities was also examined. This study is the largest study of its kind and approximately triples the available physician pre-hospital intubation data.

Lastly I report on an international consensus process that I co-chaired that was formed to try and establish what data should be collected to enable collaborative studies and valid inter-EMS comparisons to be made. This type of process is, I believe, an important step towards collecting higher quality data to inform future practice.

Chapter 3.2 Is there a requirement for advanced airway management in the pre-hospital phase of care?

3.2.1 INTRODUCTION

This study was performed to establish the frequency of airway compromise in trauma patients attended by my pre-hospital service in London. The provision of advanced airway skills with the provision of a doctor-paramedic team capable of all advanced airway interventions (including pre-hospital anaesthesia and surgical airway interventions) is a costly and scarce resource and it is important to understand whether there is a demand for these skills in addition to those provided by ambulance service personnel. In addition, the previous chapter has highlighted that the variations in EMS organisation, case mix and provider skill levels make it difficult to generalise between systems and estimate demand from the published data from other systems. To address this question in the EMS system in which I work, I attempted to establish whether available standard paramedic airway interventions (oxygen, oral / nasal airway, chin lift / jaw thrust, bag-valve-mask ventilation, supraglottic airway insertion and intubation without drugs) dealt adequately with identified airway compromise. Although there is a perception that advanced airway management is required for some trauma patients on scene there is no recently published data that attempts to quantify the demand in UK practice. This simple study addresses this knowledge gap.

3.2.2 METHODS

Over a period of one year (April 2012 – March 2013) all pre-hospital trauma patients attended by the doctor-paramedic LAA team who were identified as

having airway compromise or an indication for any airway intervention on scene were included in a prospective observational study.

In addition to standard clinical data collection, the doctor-paramedic team were asked to agree and record any airway compromise at the point of their arrival on scene and any interventions which had been carried out by ambulance service personnel in order to manage the airway. This was an attempt to determine whether any remaining compromise was due to the interventions being ineffective or because (for whatever reason) the appropriate interventions had not been attempted. The type, success and resulting complications of interventions carried out subsequently were also recorded. The ambulance service has stopped training paramedics the skill of intubation without drugs (197) but some paramedics retain this skill. During the study period both standard laryngeal mask airways™(Intavent Direct Ltd, Old Amersham, UK) and the I-Gel™ (Intersurgical Ltd, Wokingham, UK) airway were used as supraglottic airways by ambulance service paramedics.

Airway compromise was defined as: evidence of partial or complete airway obstruction on clinical examination, gross visual contamination of the airway with vomit or blood and incorrectly or displaced airway adjuncts causing airway obstruction. Airway interventions were defined as: administration of oxygen, manual airway manoeuvres – chin lift or jaw thrust, insertion of oral or nasal airways, insertion of supraglottic airways and tracheal intubation.

The local research and development department viewed the project proposal and after discussion the project was categorised and registered as a service evaluation project. No interventions were carried out and the study was

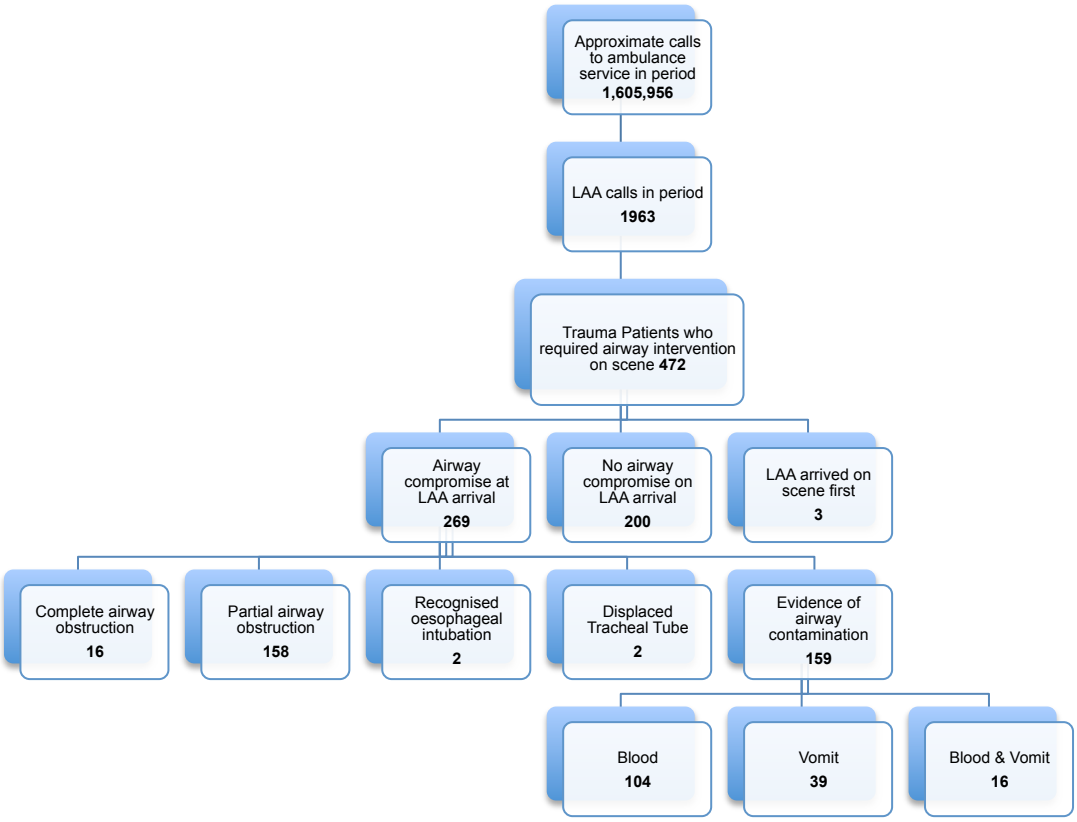
recording the frequency of events in normal practice with a view to service improvement. Ethical approval was therefore not required.

3.2.3 RESULTS

A total of 1963 patients were attended by LAA in the one year study period (1st April 2012 – 31st March 2013). Four hundred and seventy-two patients (24.0% of patients attended) had airway compromise or required advanced airway management interventions on scene (thus meeting the study inclusion criteria). Of these, 368 were male and 104 female. Mean age was 40 years (range 0 – 95). The most common mechanisms of injury were road traffic collision 187 (39.6%), falls 137 (29%) and assaults 50 (10.6%). Ninety-four patients died on scene.

On arrival of the LAA doctor-paramedic team, 469 of the included patients had ambulance service personnel in attendance. On three occasions, LAA arrived on scene first. Of 469 patients 269 (57%) had airway compromise at the point of arrival of the enhanced care team. The nature of the compromise recorded is shown in figure 3.1 below.

Figure 3.1 Airway compromise in study population



(Some patients had more than one type of compromise documented so the numbers of patients in the compromise categories add up to more than the total number with compromise)

Ambulance service airway management

Of the 469 patients attended first by the ambulance service 1,113 airway interventions had been attempted. These are recorded in table 3.1 below. 0f the 200 patients who had no airway compromise on the arrival of LAA, 134 (67%) had received ambulance service airway interventions.

Table 3.1 Ambulance service airway interventions carried out before LAA arrival

Interventions carried out	Number
Oxygen	417
Chin lift/ Jaw thrust	208
Oral/Nasal Airway	163
BVM Ventilation	134
I-Gel™	39
LMA™	13
Intubation without drugs	45
Suction to airway	94

The application of oxygen is mandatory for all seriously injured patients. Fifty-two patients (11%) had no oxygen applied before LAA arrival. Of the 269 patients who had airway compromise on LAA arrival, 174 had complete or partial airway obstruction and 145 had gross contamination with blood or vomit. The frequency of the most relevant airway interventions was examined in these two groups in more detail. The results are in figures 3.2 and 3.3 below.

Figure 3.2: Ambulance service interventions carried out in patients with complete or partial airway obstruction

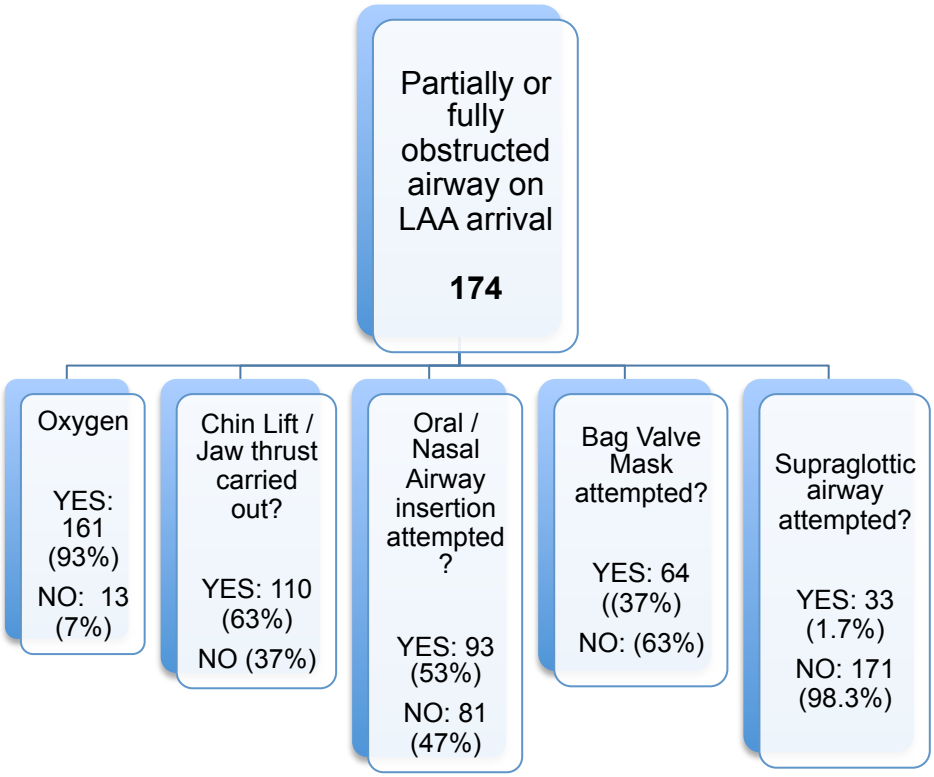
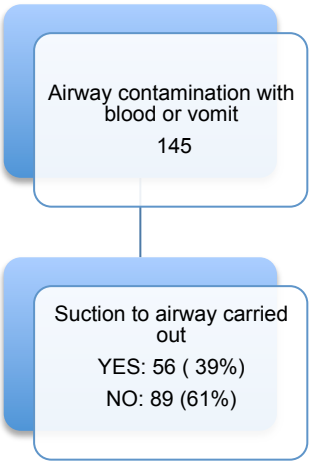
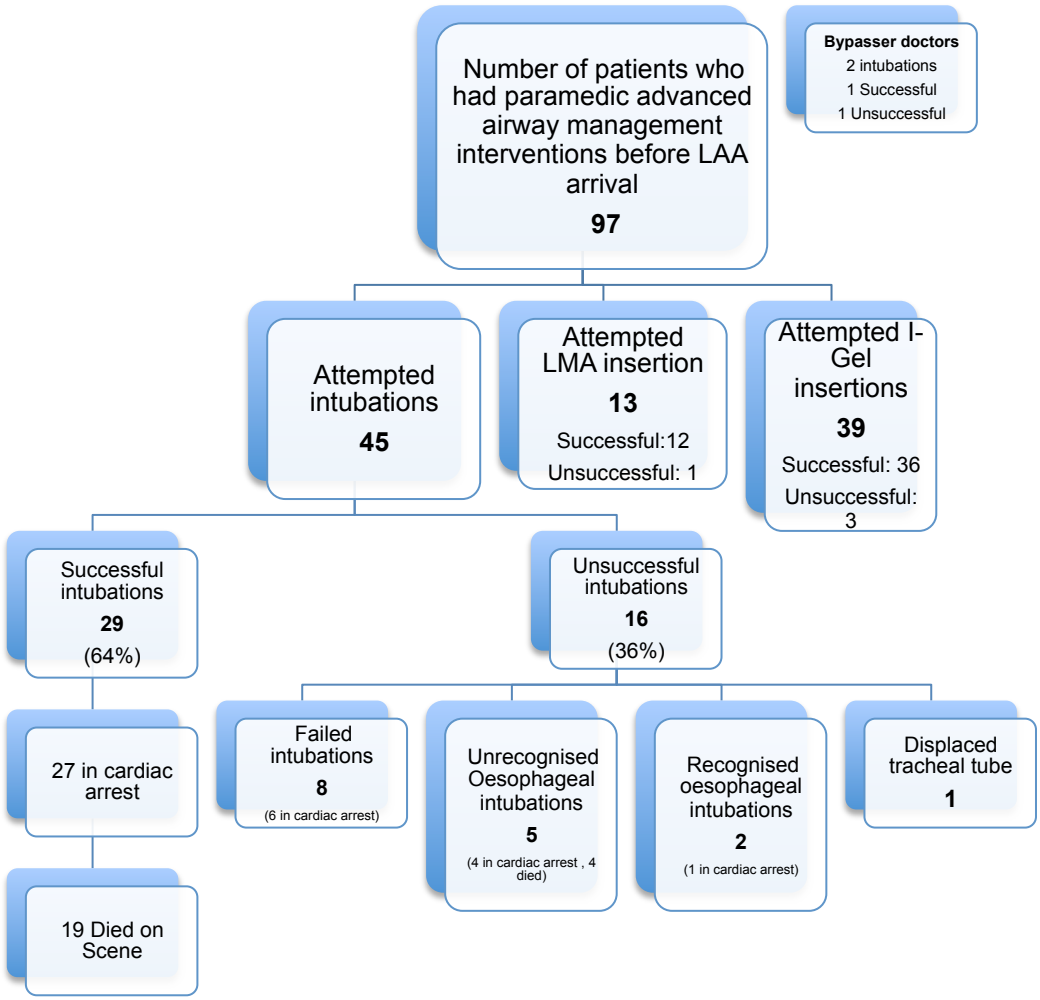


Figure 3.3 Ambulance service interventions carried out in patients with airway contamination with blood or vomit.



Ninety seven patients had advanced airway interventions carried out by ambulance service paramedics prior to LAA arrival. The results of these interventions are shown in figure 3.4 below. Overall 48 out of 52 supraglottic airway insertions (92%) were successful. There were 45 attempted intubations, of which 29 (64%) were successful. Of those that were successful, 27 (93%) were carried out in patients in established cardiac arrest. Sixteen of the 45 attempted intubations (36%) were unsuccessful. There were five unrecognised oesophageal intubations which were only identified after LAA attendance and two oesophageal intubations which had been recognised but not rectified until LAA attendance.

Figure 3.4 Paramedic advanced airway interventions



LAA airway management

Thirty nine doctors attended the patients in this study. Two hundred and forty-seven patients (52.3%) were attended by non-anaesthetists and 225 (47.7%) by anaesthetists. Overall, 58% of cases were attended by fast response car and 42% by helicopter. The mean time to arrival on scene was 28 minutes and 22 seconds (range 4 minutes – 106 minutes) and mean time on scene was 34 minutes and 48 seconds (range 4 minutes – 113 minutes).

All patients had successful pre-hospital intubation by the enhanced care team before transport to hospital. The recorded indications for pre-hospital intubation or anaesthesia and intubation are recorded in table 3.2 below.

Table 3.2 LAA indications for intubation (some patients had more than one indication)

Decreased level of consciousness	270 (57%)
Hypoxaemia	46 (9.7%)
Ineffective ventilation	88 (18.6%)
Existing airway obstruction	29 (6.1%)
Impending airway obstruction	49 (10.3%)
Combative or uncooperative	112 (23.7%)
Relief of pain or distress	29 (6.1%)
Cardiopulmonary arrest	127 (26.9%)

The group of patients who had no ambulance service airway interventions and did not have airway compromise on LAA arrival but were anaesthetised (66 patients) were all in the ‘combative or uncooperative’ or ‘relief of pain or distress’ categories.

Choice of anaesthetic agents is dictated by service standard operating procedures but most patients had a standard rapid sequence induction with induction agent, opioids and neuromuscular blocking agent (NMBA). Haemodynamically unstable patients may have the opioid omitted and patients in cardiac arrest are usually intubated without the use of drugs. The use of drugs in this study population are shown below in table 3.3.

Table 3.3 Drugs used to facilitate intubation by LAA

Induction agent	326
NMBA	338
Analgesics/ opioids	279
None	126

Recorded complications of advanced airway management by the enhanced care team included four tracheal tubes recognised as misplaced in the oesophagus. All were corrected prior to finishing laryngoscopy. Three right mainstem bronchus intubations were also identified and corrected before leaving scene. In addition there were 13 reports of vomiting or aspiration before or during intubation, 19 reports of hypoxia (SpO_2 <90%), one of bradycardia (heart rate < 50) and 15 reports of post induction hypotension (systolic blood pressure < 90 mmHg).

Table 3.4 Reported LAA problems on scene

Recognised oesophageal intubation	4
Recognised mainstem bronchus intubation	3
Unrecognised oesophageal intubation	0
Trauma to teeth	0
Vomiting and/or aspiration	13
Hypoxia	19
Bradycardia	1
Hypotension	15

3.2.4 DISCUSSION

The results of this prospective study demonstrate that airway compromise is frequent in the group of patients attended by my pre-hospital trauma service. The demographics of the study are as expected – mostly blunt trauma in a young male population. The high rate of cardiac arrest and death on scene also confirm the high severity of injury in the study population. This finding is in

keeping with other studies which record airway compromise in trauma patients in the pre-hospital phase of care (201) or on arrival at the emergency department (125). UK data is scarce but the National Confidential Enquiry into Patient Outcome and Death report 'Trauma Who Cares' which was published in 2007 (17) did report that 12.6% of major trauma patients arrived in the emergency department with a partially or completely obstructed airway and had a higher mortality. Although the reported rate of airway compromise is high in this group this has to be viewed in the context of a huge number of calls to the ambulance service in the same period. Significantly injured trauma patients with airway compromise are therefore uncommon in routine paramedic practice. As a result most paramedics perform few advanced airway interventions per year (197) unless they operate in targeted enhanced care teams. This study attempted to establish whether ambulance service airway interventions dealt adequately with trauma patients with airway compromise on scene. The results presented show that 57% of patients still had compromise on arrival of the LAA doctor-paramedic team. The doctor-paramedic team secured the airway prior to leaving scene in all of the compromised patients. This strongly suggests that there is a requirement for enhanced care for this small group of patients that is not currently met by ambulance service provision. There are potential limitations to the reliability of these conclusions. The time between ambulance service arrival and LAA arrival may have been variable and there may not have been time for paramedics to effectively deal with airway compromise. However during the study period the ambulance service attended more than 75% of high priority calls within 8 minutes (202) and the mean time to arrival at scene by LAA was more than 25 minutes (the prolonged time to scene is probably due to the fact

that many of the calls were attended by fast response car rather than by helicopter). In addition although the nature of airway compromise is documented the degree of compromise and the consequences of not treating each patient is not. There is little written about the nature of airway contamination in trauma patients but the findings of this study that gross airway contamination is mostly from blood (from above) rather than vomit (from below) is in keeping with a previous study from our system (203). If these findings are a true reflection of this patient group then they suggest that supraglottic airways could provide a degree of protection against aspiration since supraglottic airways do provide a degree of protection from upper airway soiling.

The airway management by the ambulance service is important. The study demonstrates that standard ambulance service was only effective for a proportion of patients. This could be because the interventions available are not effective for this patient group but this is only true if the available interventions were applied appropriately and consistently to the patients with compromise. It is likely that a proportion of those that had airway interventions performed before LAA arrival and had no compromise on LAA arrival were treated effectively. The data collected does suggest that airway management was sub-optimal in a considerable number of cases. Failure to apply oxygen in a very short time is a serious omission. This occurred in 11% of patients. As mentioned above the degree of compromise is not recorded but the considerable proportion of patients with airway obstruction who did not have basic airway manoeuvres attempted is concerning. Similarly the number of patients with gross blood and / or vomit contamination of the airway who had no attempts at suction is surprising.

Ninety four patients had advanced airway interventions attempted by ambulance service paramedics. These consisted of supraglottic airway insertion and intubation without drugs. The supraglottic airway insertion success rate is high (92%) and in keeping with previously published pre-hospital success rates (204). The attempted intubations had a high failure rate (36%) and significant complications. Unrecognised oesophageal rates of more than 10% (even in cardiac arrest) are unacceptable (97) and although the numbers in this study are small they provide more evidence that intubation without drugs by paramedics may do more harm than good. The successful intubations without drugs were virtually all in traumatic cardiac arrest patients and benefit has been previously seriously questioned in this patient group (19) . The data presented do suggest that the move by this ambulance service and JRCALC (197) to stop training paramedics intubation without drugs is the correct one.

The data presented from this study suggest that current ambulance service provision does not meet the needs of the seriously injured patient with airway compromise. A doctor –physician team with RSI capability do appear to be able to successfully manage airway compromise although complications still occur regularly in this high risk patient group.

3.2.5 STUDY LIMITATIONS

Key limitations have already been discussed above. They include the fact that the exact time that the ambulance service had on scene to resolve airway problems before arrival of the doctor-physician team is likely to have been variable. Also the fact that airway compromise was present was subjective although the exact nature of the compromise was recorded and the doctor and

paramedic were asked to agree on this prior to recording it. An attempt was made to assess whether patients with compromise were compromised after standard management interventions had been carried out or when (for whatever reason) standard management had not been attempted. It may not always have been possible to establish which interventions had been attempted prior to the assessors arrival. There may have been bias from under or over self reporting of complications of advanced airway management of the attending doctor-paramedic team.

Chapter 3.3 Is there a difference between physician and paramedic intubation success?

3.3.1 INTRODUCTION

The previous two chapters have commented on the controversy surrounding pre-hospital intubation and the last chapter highlighted the poor intubation success of paramedics operating without drugs in a small number of trauma patients. This chapter describes a comprehensive metaanalysis which was designed to establish whether the published literature indicates a difference in ETI success rates between physician- and non-physician-manned EMS systems. The success rates of non-physicians and physicians were compared and also those of non-physicians using different levels of drug assistance to intubate. In addition, whether there was a difference in ETI success rates between physicians and the sub-group of non-physicians using a muscle relaxant or a standard RSI was also investigated.

Although there are a number of factors that determine the quality of pre-hospital anaesthesia the rate of successful placement of a tracheal tube into the trachea after attempted intubation, particularly after the administration of a muscle relaxant, is recognised as a quality indicator for systems practicing ETI. Although muscle relaxants are administered to facilitate intubation they also render the patient apnoeic and therefore make the consequences of failed intubation much more serious.

3.3.2 METHODS

Identification and selection of studies

A systematic search of Medline and EMBASE was carried out according to the PRISMA guidelines (34). I identified all original English-language articles

published prior to 1 September 2009 that related to pre-hospital ETI in adult patients (159). The studies that investigated paediatric cohorts, focused on surgical airways or compared ETI to other airway devices were excluded. The reference lists of the included studies and a relevant Cochrane review (205) were inspected to identify any additional relevant studies. The search strategy is shown below:

Search strategy for identification of relevant studies in Medline and EMBASE

Search terms "keywords":

Medline	"Emergency Medical Services" AND "Intubation, Intratracheal"
Embase	"emergency care" AND "intubation/ or respiratory tract intubation"

Search terms "title"

Medline	"prehospital" AND "intubation"
	"pre-hospital" AND "intubation"
	"out-of-hospital" AND "intubation"
	"prehospital" AND "RSI" OR "Rapid sequence induction"
	"pre-hospital" AND "RSI" OR "Rapid sequence induction"
	"out-of-hospital" AND "RSI" OR "Rapid sequence induction"
EMBASE	"prehospital" AND "intubation"
	"pre-hospital" AND "intubation"
	"out-of-hospital" AND "intubation"
	"prehospital" AND "RSI" OR "Rapid sequence induction"
	"pre-hospital" AND "RSI" OR "Rapid sequence induction"
	"out-of-hospital" AND "RSI" OR "Rapid sequence induction"

Study eligibility criteria and data extraction

From the initial search, I selected all of the studies reporting ETI success rates. From these papers, I extracted information on the numbers of attempted ETIs and successful ETIs, type of provider, level of ETI training and drug availability on scene. The providers were categorised into two groups: physician and non-physician. The use of drugs was categorised into three groups: 1) no drugs

available; 2) analgesics, anaesthetics, or a combination; and 3) muscle relaxants, with or without co-administration of analgesics and anaesthetics, or a standard RSI.

Statistical meta-analyses

The ETI success rates are reported as medians (range) unless stated otherwise. The individual and overall success rate is presented in a forest plot, and the overall success rate was calculated using a random effects meta-analysis for proportions. The analysis did not consider the number of ETI attempts before success was achieved.

To assess the relationships between the ETI success rate and provider type, and between the ETI success rate and type of drugs available on the scene, a weighted univariate linear regression analysis was performed with the ETI success rate as the dependent variable and drug availability and provider type as categorical independent variables. The regression was weighted by the size of each study, i.e., by the number of intubation attempts. As all physicians use RSI (drug group ‘3’), a multiple regression model would have been degenerate and was not performed. All the tests were two-tailed, and statistical significance was indicated by $p<0.05$. The data were analysed using R 2.12 (The R Foundation for Statistical Computing, Vienna, Austria).

Study ethics

As a meta-analysis based on a systematic literature review, this study did not require ethical approval.

3.3.3 RESULTS

From 1070 studies initially retrieved through the systematic search, 58 original studies were identified that met the inclusion criteria. Of these, 45 (78%) were studies of non-physician-manned services (paramedic- or paramedic/nurse-manned). Twenty-nine (64%) of the 45 non-physician-manned services and seven (54%) of the 13 physician-manned services reported ETI success rates. The success rate reporting was incomplete in three studies from non-physician-manned services, leaving 33 studies for the final analysis (Figure 3.5). An overview of the included studies is shown below in Table 3.5.

Figure 3.5 Results of literature search

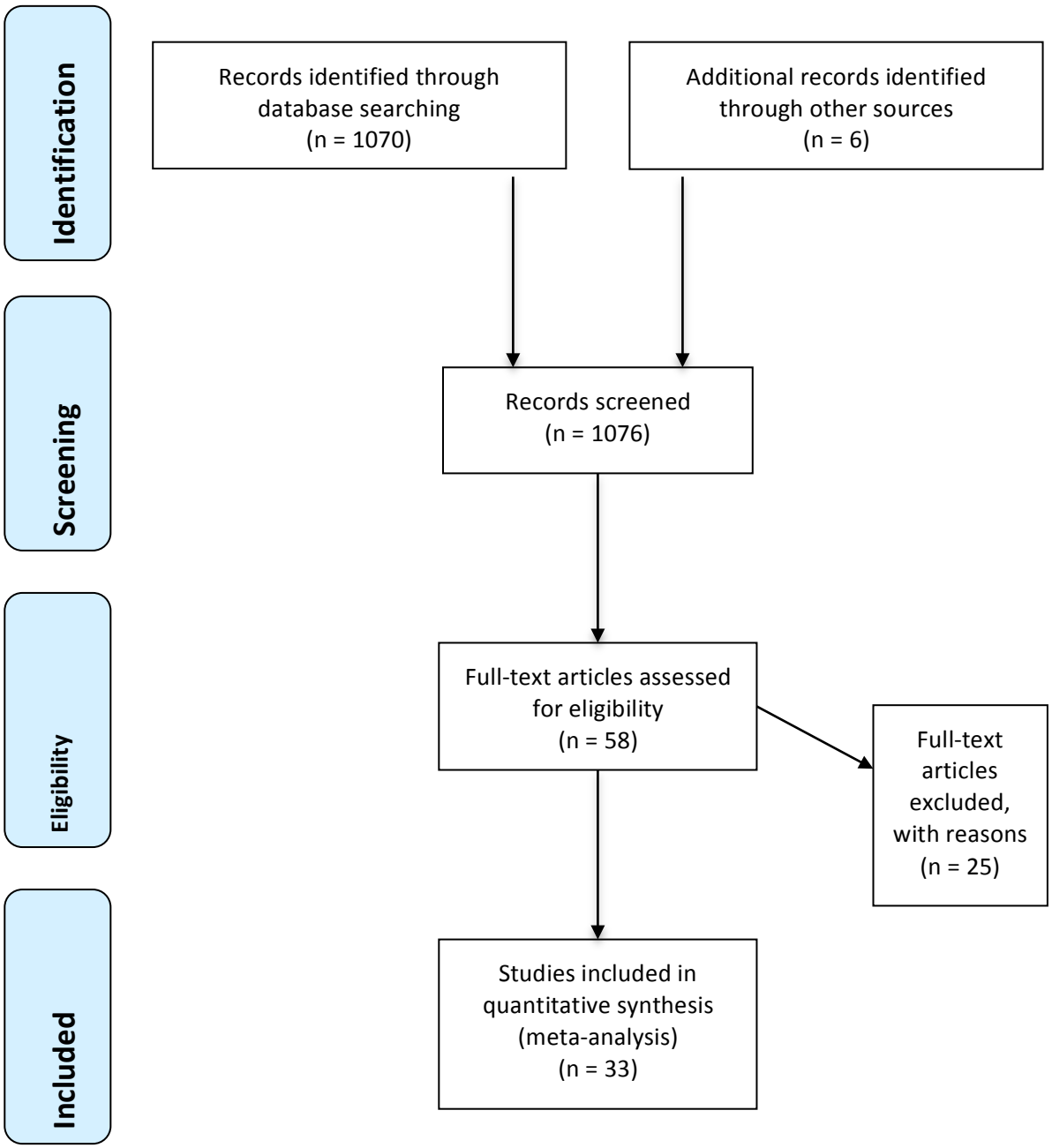


Table 3.5 Overview of included studies in systematic review

Study	Aim of Study	EMS manning	Drugs available?	ETI Attempts	Success rate
Adnet F, *Ann Emerg Med* 1998, **32**:454-460.	To analyze prehospital ETI in a large French urban setting and(2) to establish the specific characteristics of performance of ETI in the SAMU compared with those reported from Anglo-Saxon paramedic systems.	Anaesthetists or emergency physicians.	RSI	691	
BozemanWP, *Presp Emeg Care* 2006,**10**:8-13.	To evaluate the lanyngoscopy conditions produced by two commonly used medication regimens in a multi aircraft air medical program.	Nurse/paramedic	Analgesics/ anaesthetics	62	0.790
Bradley JS *Ann Emerg Med* 1998, **32**:26-32.	To determine the success and complication rates of prehospital orotracheal intubation by rural EMT-Bs who underwent didactic and manikin training.	Paramedics without previous experience in intubation	No drugs available	57	0.491
Cantineau JP, *Ann Fr Anesth Reanim* 1997, **16**:878-884.	To investigate complications of PH emergency ETI, possibly facilitated by RSI: 1) the difficulty of ETI ; 2) the cardiorespiratory consequences of ETI ; 3) the relationship between the occurrence of complications and prognosis.	Anaesthetists.	RSI	224	1.000
Cobas MA, *Anesth Analg* 2009, **109**:489-493.	We postulated that failure to intubate the trachea in the prehospital setting would translate into increased mortality when compared with those patients who were successfully intubated.	Paramedics trained in intubation	RSI	203	0.689
Colwell CB, *Acad Emerg Med* 2005, **12**:417-422.	To determine the success and complication rates associated with endotracheal intubation in an urban emergency medical services (EMS) system.	Paramedics extensively trained in intubation.	No drugs available	124	0.968
Davis DP *J Trauma* 2003, **55**:713-719.	To determine the impact of paramedic-administered neuromuscular blocking agents on airway management for all severely head-injured patients in a large, urban prehospital system.	Nurse/paramedic	RSI	249	0.855
Davis DP *J Emerg Med* 2005, **29**:391-397.	The primary goal of this analysis was to explore the relationship between paramedic GCS score calculations and head-injury severity, the presence of factors related to the need for intubation such as hypoxia and aspiration, and eventual outcome.	Paramedics trained in intubation	RSI	412	0.850
Denver MASG: *Prehosp Emerg Care* 2009, **13**:304-310.	To determine paramedic intubation success and malposition rates in a large metropolitan EMS system that includes 18 hospitals and 34 transporting EMS agencies.	Nurse/paramedic	No drugs available	825	0.748
Eckstein M, *J Trauma* 2000, **48**:643-648.	To determine the impact of prehospital ETI versus BVM on the outcomes of major trauma patients.	Paramedics with, variuos training.	No drugs available	148	0.630
Fakhry SM *J Trauma* 2006, **60**:997-1001.	To formally review the procedural experience and outcomes of prehospital units with RSI in severely injured patients with high rates of TBI. A secondary purpose was to	Paramedics extensively trained in intubation	RSI	175	169 0.966

	explore possible explanations for divergent results between our program and other recent reports.					
Frankel H, *Am J Emerg Med* 1997, **15**:630-632.	The author hypothesized that field OI in this urban setting with short transport times would have a favorable impact on both outcome variables.	Paramedics trained in intubation	Analgesics/anaesthetics	58	47	0.810
Gunning M*Emerg Med J* 2009, **26**:65-69.	To describe the safety profile of emergency airway management when performed by a prehospital team consisting of a doctor and a paramedic.	Anaesthetist, emergency physician or intensivist.	RSI	114	111	0.976
Helm M, *Br J Anaesth* 2006, **96**:67-71.	The purpose of this study was to evaluate, within the German Helicopter Emergency Medical Service (HEMS) system, which is a physician based EMS system, the success rate of, and adverse factors influencing, pre-hospital ETI.	Experienced trauma anaesthetist.	RSI	342	342	1.000
Jacoby J*Ann Emerg Med* 2006, **47**:525-530.	To compare the success rate of etomidate and midazolam for sedative-facilitated intubation in out-of-hospital adult patients, and to compare the safety and perceived difficulty of intubation with the 2 drug regimens.	Paramedics with, variuos training.	Analgesics/anaesthetics	110	83	0.755
Karch SB *Am J Emerg Med* 1996, **14**:617-619.	To determine whether the outcome in trauma patients intubated in the field was any different from that of patients with similar injuries intubated at our hospital.	Paramedics with, variuos training.	No drugs available	94	62	0.660
Mackay CA *Emerg Med J* 2001, **18**:20-24.	To study pre-hospital rapid sequence induction of anaesthesia to determine if there were differences in practice between anaesthetists and A&E physicians, and to document difficulties encountered and intubation mishaps.	Emergency physician or anaesthetist.	RSI	359	353	0.983
McIntosh SE *Prehosp Emerg Care* 2008, **12**:438-442.	To compare circumstances and success rates of air medical team intubations based on location, patient characteristics, and type of aircraft.	Nurse/paramedic extensively trained in intubation.	RSI	694	655	0.944
Murray JA *J Trauma* 2000, **49**:1065-1070.	To evaluate the outcome of patients with severe head injury requiring pre-hospital intubation and to determine whether pre-hospital intubation is associated with an improved outcome.	Paramedics trained in intubation	No drugs available	138	81	0.587
Ochs M, *Ann Emerg Med* 2002, **40**:159-167.	Our primary objective was to demonstrate the feasibility of paramedic use of RSI that included neuromuscular blocking and sedative agent administration, with particular focus on intubation success, physiologic parameters, and complications.	Nurse/paramedic extensively trained in intubation.	Muscle relaxant	114	96	0.842
Rhee KJ, *Ann Emerg Med* 1994, **23**:37-42.	The purpose of this study was to compare the effectiveness of NMB-assisted oral intubation and NTI in a population of severely injured patients requiring endotracheal intubation in the field.	Nurse extensively trained in intubation.	Muscle relaxant	33	25	0.758

Sing RF *Am J Emerg Med* 1998, **16**:598-602.	This study describes the use of a strict protocol for RSI and characterizes intubation mishaps, subsequent pulmonary complications, and outcome by this aeromedical transport team using RSI for definitive airway control.	Nurse/paramedic extensively trained in intubation.	RSI	84	81	0.964
Slagt C *Air Med J* 2004, **23**:36-37.	To get a better insight into the patient population in which endotracheal intubation was performed in the prehospital setting.	Anaesthetist.	RSI	653	648	0.992
Sonday CJ *Prehosp Disaster Med* 2005, **20**:324-326.	To compare the use of THIO with that of ETOM as the sedative agent used in conjunction with SCh for RSI in an aeromedical environment.	Nurse/paramedic extensively trained in intubation.	RSI	98	97	0.990
Swanson ER, *Prehosp Emerg Care* 2004, **8**:273-279.	To compare etomidate with midazolam as sedative or induction agents for RSI in our air medical transport system.	Nurse/paramedic extensively trained in intubation.	RSI	209	206	0.986
Tam RK *Prehosp Emerg Care* 2009, **13**:311-315.	To examine the prehospital ETI practice and relative success rate when ETI is attempted for patients of all ages within a Canadian EMS system.	Paramedics, various training.	No drugs available	1029	845	0.821
Swanson ER, *Air Med J* 2002, **21**:28-31.	To determine the impact of an AEP on prehospital intubation by an air medical service and identify factors associated with failed intubation.	Nurse/paramedic extensively trained in intubation.	RSI	372	356	0.957
Timmermann A *Anesth Analg* 2007, **104**:619-623.	To determine the incidence of misplaced tracheal tubes when tracheal intubation was performed out-of-hospital by a primary emergency physician(s), as evaluated by study emergency physicians at the scene of the medical emergency.	Primary emergency physicians.	RSI	153	149	0.974
Vadeboncoeur TF *J Emerg Med* 2006, **30**:131-136.	To explore the timing of aspiration in patients with TBI.	Paramedics extensively trained in intubation	Muscle relaxant	263	223	0.848
Wang HE, *Prehosp Emerg Care* 2001, **5**:10-18.	To evaluate the impact of patient clinical status on prehospital ETI success rates.	Paramedics, variuos training.	Analgesics/anaesthetics	893	771	0.863
Wang HE, *Prehosp Emerg Care* 2001, **5**:134-141.	To identify patients who could not be intubated in the field and to describe the methods subsequently used in the ED to manage the airway.	Paramedics, variuos training.	Analgesics/anaesthetics	592	536	0.905
Warner KJ, *Prehosp Emerg Care* 2010, **14**:103-108.	To comprehensively evaluate a large cohort of patients undergoing pre-hospital ETI with and without RSI, and specifically describe the occurrence, presentation, and management of the difficult airway and explore consequences of airway failure.	Paramedics extensively trained in intubation	RSI	4091	3961	0.968
Wayne MA, *Prehosp Emerg Care* 1999, **3**:107-109.	To determine the safety and efficacy of succinylcholine, as an adjunct to endotracheal intubation, administered by paramedics trained in its use.	Paramedics trained in intubation	Muscle relaxant	1735	1657	0.955

EMS - emergency medical service ETI - emergency tracheal intubation RSI - rapid sequence induction

In total, ETI was attempted in 15,398 patients: 2,536 by physicians and 12,862 by non-physicians. The median (range) reported success rate was 0.905 (0.491, 1.000). The estimated overall (95% CI) ETI success rate was 0.927 (0.882, 0.961). Figure 3.6 presents the individual study estimates and corresponding 95% CIs.

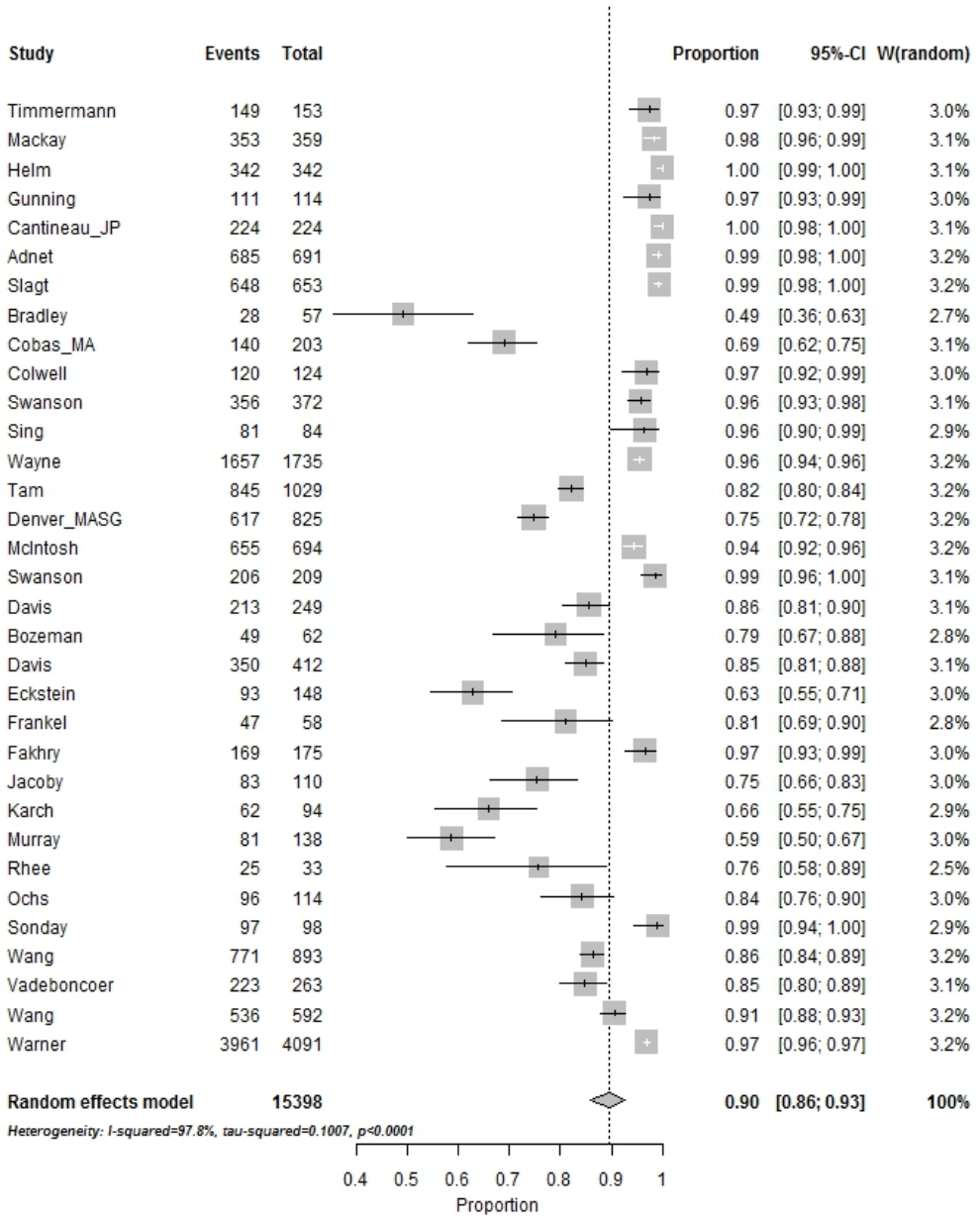
When comparing physicians to non-physicians, the corresponding median (range) ETI success rates were 0.991 (0.973, 1.000) vs. 0.849 (0.491, 0.990). All seven physician-manned services reporting success rates also reported drugs available on the scene (all used standard RSI). Of the 26 non-physician-manned services reporting success rates, 19 (73%) reported drugs available on scene, leaving seven services reporting no use of drugs (drug group 1). Of the 19 services reporting use of drugs, six had analgesics, anaesthetics or a combination available (drug group 2), and 13 reported having muscle relaxants, with or without analgesics or anaesthetics, or standard RSI available (drug group 3). In drug groups 1, 2 and 3, the reported median (range) ETI success rates for non-physicians were 0.675 (0.491, 0.968), 0.810 (0.755, 0.905) and 0.967 (0.758, 1.000), respectively.

In weighted linear regression analysis, having physician providers was significantly associated with an increased success rate: 0.092 (0.007, 0.176), p=0.0345. Similarly, drug groups 2 and 3 were significantly associated with an increased success rate: 0.108 (0.033, 0.183), p=0.006, and 0.199 (0.147, 0.252), p<0.001, respectively.

When comparing physician to drug group 3 (muscle relaxants, with or without analgesics or anaesthetics, or standard RSI available) non-physician success

rates, there still was a significant difference in favour of physicians: 0.991 (0.974,1.000) and 0.955 (0.758,0.990) respectively (p=0.047).

Figure 3.6 ETI Success Rates



3.3.4 DISCUSSION

Airway management in pre-hospital care is complex. Although ETI is only required in a small number of critically ill or injured patients (17,125), it is a well-

established tool in pre-hospital EMS services. The procedure carries a risk of severe adverse events if not performed correctly (206), and its providers must be both technically competent to perform the procedure and capable of making decisions and initiating treatments to prevent or treat complications. The ETI success rate is only one component of successful pre-hospital airway management, but a system that performs ETI should strive for a high success rate.

This meta-analysis demonstrates that when non-physicians attempt pre-hospital ETI, they have significantly higher intubation failure rates than physicians. The ETI failure rate of physician-manned services was on average one out of 100 patients**,** whereas services manned by non-physicians failed on average in 15 out of 100 patients.

This overall comparison between physician- and non-physician-manned services is important. There is undoubtedly considerable variation in the experience and skill levels covered by both the term ‘physicians’ and the term ‘non-physicians’. The exposure to situations requiring ETI in the pre-hospital setting is in most EMS services relatively uncommon, and it can be argued that it is often insufficient to maintain necessary skills. Nevertheless, physicians operating in pre-hospital EMS are likely to have had more training and have performed a greater number of intubations than non-physicians due to their in-hospital clinical activity. In the in-hospital setting, emergency physicians and anaesthetists often perform emergency and elective intubations on a regular basis. Much more relevant to patient safety is the comparison between physicians and non-physicians when muscle relaxants have been administered to facilitate intubation. Failure to achieve intubation after rendering a patient

apnoeic has major safety implications, and carries a risk of hypoxic brain injury and death (207). Reports of ETI failure rates of over 15% after administering muscle paralytics are not uncommon in non-physician systems (200,208,209). This high failure rate has been previously highlighted (97); it is not only unthinkable in hospital practice, but is unacceptable in any area of practice. Even though the inclusion of muscle relaxants in non-physician-manned EMS services providing ETI appears to significantly improve intubation success rates it also results in five patients in every 100 being rendered apnoeic with an unsecured airway after failed intubation.

The precise clinical implications of these findings are difficult to assess. Failed intubations in hospitals have been subject to considerable analysis, which may give an indication of the consequences of failed pre-hospital intubation. A recent study (210) collected reports of major airway management complications during anaesthesia (death, brain injury, emergency surgical airway, and unanticipated intensive care unit admission) from all of the UK National Health Service hospitals over one year. Difficult or delayed intubation, failed intubation, and ‘can’t intubate, can’t ventilate’ accounted for 39% of all such events. In a USA study of 179 closed claims arising from managing difficult airways, the majority (67%) of the incidents resulting in death or brain damage involved the induction phase of anaesthesia and were clearly associated with intubation difficulties (207). It seems that failed intubation is closely associated with the most devastating complications of airway management. In healthcare risk assessment, the significance of a failed intubation and its consequences can be assessed by answering a few key questions (211): what can go wrong; how bad is it; how likely is it to occur; and what can we do about it? We know what can

go wrong in failed pre-hospital intubation, and we know the consequences that fall into the potentially ‘catastrophic’ category (death or severe disability). When constructing a ‘risk matrix’, the only other key information required is the frequency or likelihood of the event occurring in a given system. The results of combining the potentially severe consequences from failed intubation assisted by muscle relaxants and our observed frequency of failed intubation in ‘non-physician’ systems falls into in an ‘extreme risk’ category in the NHS National Patient Safety Agency's patient safety guidance risk matrix (211). ‘Extreme risk’ requires urgent action by the highest level of an organisation. If the data presented in this review were used in the planning phase of a study comparing the outcomes of pre-hospital airway management in physician and non-physician systems, ethical approval would be difficult to obtain.

One of the principles of recent pre-hospital anaesthesia guidelines is that patients undergoing pre-hospital anaesthesia should have the same standards of care and safety that they would receive in an emergency department (158). This review suggests that physician-conducted pre-hospital intubation is associated with high levels of success that are similar to those reported in USA emergency departments (124). ETI attempted without drugs has not been associated with improved outcomes in cardiac arrest patients (212) and is only likely to be achieved in trauma patients with a high probability of mortality (19). In previous studies of failed intubations in paramedic systems (213), it has been suggested that insufficient training of the operators rather than their professional status may be responsible for the poor outcomes. Efforts have been made to train non-physicians in critical care (214,215). Equipping non-physicians with drugs and training them to conduct RSI raises a number of difficulties that need

to be overcome. Both training and skill retention are likely to be difficult, as using elective anaesthetic techniques without the need for intubation is becoming more frequent (215). It is also important to ensure that the individuals trained to perform the complex RSI procedure are matched with the few patients that require it and to provide the considerable resources necessary to run such programmes. If all of these obstacles are overcome and significant resources are provided to train non-physicians to a high level, what failure rates can be expected? When the success rates of non-physicians trained to perform RSI were compared with the success rates of physician-manned services a significant difference in success rate remained. The 2009 study by Warner et al. (96) described an exceptionally high level of training, supervision and re-certification and reported on a relatively high number of ETIs. The paramedics were trained in a university training programme with 2500 hours of classroom, laboratory and field experience. Their ETI skills were developed through lectures, intensive mannequin training and experience with patients in the operating room. Field ETIs were then attempted with strict direct supervision and medical oversight. The paramedics also participated in a comprehensive recertification programme every two years. A minimum of twelve uncomplicated tracheal intubations per year was required for recertification, and failure to achieve this standard resulted in returning to the operating room for further supervised training. Despite their high level of training, the paramedics in this programme still failed to intubate 3 out of 100 patients after administering muscle paralytics in, (three times the failure rate of physicians) which raises significant patient safety issues.

The results of this review suggest that EMS systems in which non-physicians perform ETIs have significantly more failed intubations than systems in which physicians perform ETIs. This increase persists in non-physician systems where muscle relaxants are used and where comprehensive training is provided. If pre-hospital anaesthesia is to be conducted, it should be performed to the highest standards, which includes an intubation success rate close to 100%. This review suggests that this level of performance is currently found only in physician-manned services. Substituting existing physicians with even well trained non-physicians brings with it significant patient safety issues. It may be that where pre-hospital EMS-physicians are not available, concentrating on basic and advanced airway management techniques other than ETI should be strongly considered in a highly performing EMS system.

3.3.5 STUDY LIMITATIONS

The results of the analysis in this study must be interpreted with caution due to the small numbers in the patient sub-groups, although the findings remain significant and have narrow CI's. Selection bias, missing cases, and reporting bias in publishing may be conducive to including studies not necessarily representative of real-time clinical activity and performance. The long time frame for including studies and the variance in the reported success rate may diminish this.

This review did not consider a number of other factors that may contribute to poor outcome. Sub-optimally performed ETI, such as multiple intubation attempts, hyper- or hypoventilation and unrecognised oesophageal intubation, may be critical to outcomes and not reflected by intubation success rates. A high rate of undetected oesophageal intubation has been reported in non-

physician systems and continues even after introducing easily used carbon dioxide detection equipment (174). This did appear to be an issue in our system as described in the previous chapter. I also did not examine whether non-physicians are better or worse than physicians at managing the consequences of failed ETI. Even in physician-manned services, lack of training and sub-optimal recognition of the indications for advanced airway management may influence outcomes (216). The consensus process described in the introduction to this thesis identified pre-hospital airway management as a prioritised area for future research (22).

Chapter 3.4 How successful is physician-led advanced airway management?

3.4.1 INTRODUCTION ADULT INTUBATION

The last chapter revealed that the worldwide data available on physician pre-hospital intubation are limited, despite the fact that this intervention has been carried out on a daily basis in EMS systems throughout Europe for many years. The second chapter in this section revealed that in my EMS system paramedic airway management performed by the ambulance service does not appear to meet the needs of the small number of seriously injured patients with airway compromise. In the same prospective study the intubation rate of physicians was 100% but the number of patients was limited. This chapter describes a retrospective observational database study of London Air Ambulance physician airway management. It was conducted to establish the success rates of intubation in a physician-led system and to examine the frequency and management of failed intubation in the pre-hospital trauma patient. Intubation success and a robust intubation rescue plan (98,158) are both quality markers of an EMS system conducting RSI. I also examined whether failure rates were different between the two main groups of physician providers within the system, anaesthetists and non-anaesthetists. The study was designed to use intubation success rates as a quality indicator to establish whether the care provided by this doctor-paramedic team composition is better than paramedic care and how it compares with existing physician data.

3.4.2 METHODS - ADULT INTUBATION

A retrospective database interrogation of a pre-hospital physician–led service was carried out. The organisation of the service is discussed in Section 1.2.

Doctors are predominantly from the specialities of emergency medicine and anaesthesia. All doctors are at least five years post qualification and expected to have completed at least six months of hospital based anaesthesia and emergency medicine and have passed a relevant postgraduate diploma before commencing a pre-hospital care post. The current Standard Operating Procedure for pre-hospital anaesthesia and the technique used for surgical airway is shown in Appendix 1. The provision of pre-hospital anaesthesia was standardised in 1996 approximately five years after the service commenced. However this standardisation was only in terms of anaesthetic agents used. The use of Etomidate for induction of anaesthesia and Suxamethonium for muscle relaxation persisted until 2012. The first standard operating procedure (SOP) was written in 2000 and concentrated on simplicity and the minimisation of choice to try and achieve high intubation success rates. In 2005 a supraglottic airway was introduced into practice as an alternative to surgical airway. This was the Proseal LMA^{TM} (Intravent, Old Amersham, UK) chosen for high ventilation pressures and the presence of a gastric drainage channel to minimise aspiration. This was changed to the I-Gel^{TM} (Intersurgical Ltd, Wokingham, UK) for ease of insertion in 2010 and this device is now also used by the London Ambulance Service. Pre-induction check lists, regular moulage practice and pre-drawn anaesthetic drugs were in use by 2006. In 2012 after recognition that physiological disturbance might be better avoided in some patient groups by adopting a technique closer to that used in hospital, the current SOP was adopted. This includes the use of an opioid agent (fentanyl), ketamine for induction and a rapid but long acting muscle relaxant (rocuronium). Data were available from September 1991 to December 2012. The database is

a Microsoft Access™ (Redmond, WA USA) based program that is completed shortly after missions by attending physicians. All patients who had documented attempted advanced airway interventions were included. The database only includes trauma patients but drownings, hangings, traumatic asphyxia and inhalational injuries are attended and were included. The data were analysed with simple descriptive statistics using InStat™ (GraphPad, San Diego, USA) The Chi squared test was used to calculate the statistical significance of proportions. Statistical significance was set at $p< 0.05$.

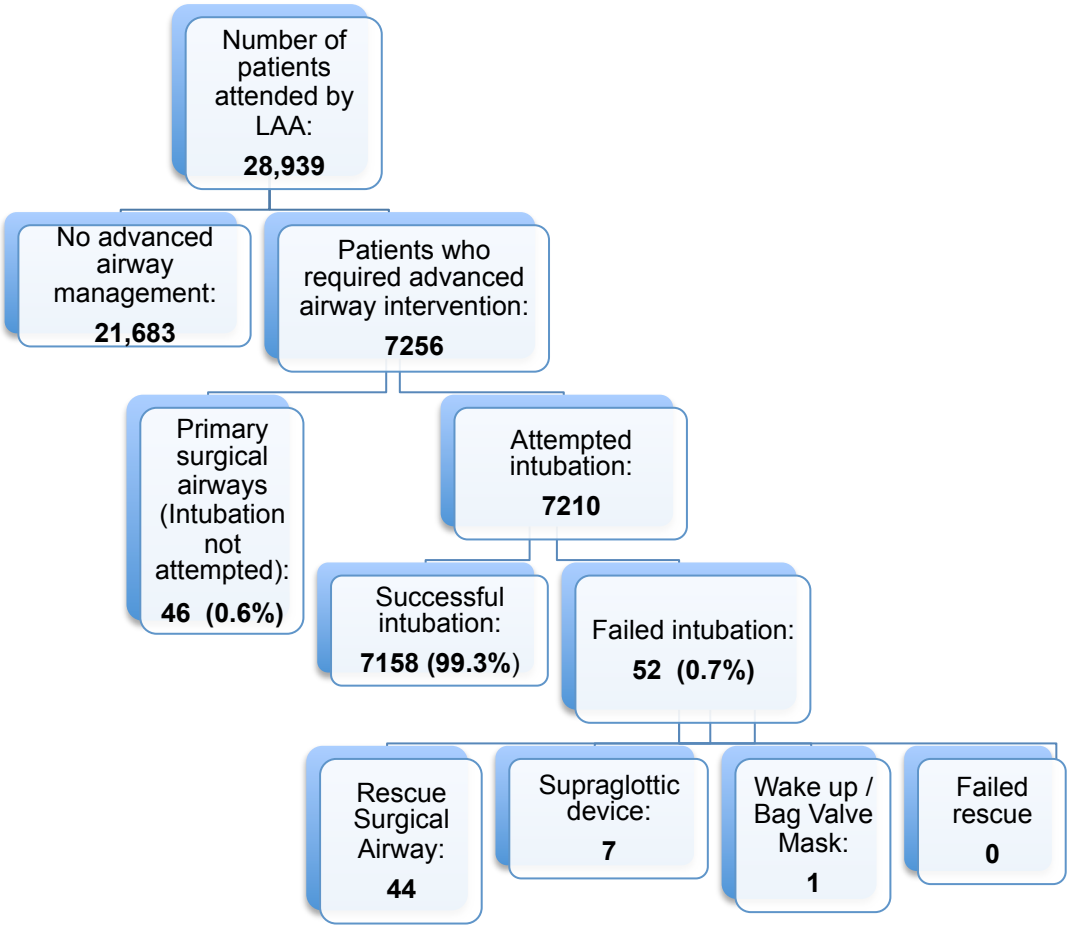
Data collected included the number of missions attended, the number of patients who required advanced airway interventions and the number of successful and failed intubations. To investigate whether individuals had different success rates the speciality of the doctors and their individual success rates were recorded. To evaluate the success of the rescue techniques the success and type of rescue intervention was recorded as well as the mechanism of injury and patient outcome.

3.4.3 RESULTS - ADULT INTUBATION

The results of this study are shown in Figure 3.7 below. In the study period, 28,939 trauma patients were attended by the London Air Ambulance doctor-paramedic team. Of these 7256 (25.1%) required intubation. In 46 patients (0.6%) immediate surgical airway was performed without any attempt at intubation. Of the remaining 7210 patients intubation was successful in 7158 (99.3%). Of the 52 patients (0.7%) who could not be intubated 44 had successful surgical airways performed and seven had successful insertion of a supraglottic device. In two patients successful supraglottic device insertion was followed by conduct of successful surgical airway before transfer to hospital.

One patient was allowed to spontaneously breathe with bag-valve-mask support during transfer to hospital.

Figure 3.7 Physician intubation and airway rescue success rates



All surgical airways (both primary and rescue) were successful. There were no airway rescue failures. Data identifying the specialty of the intubating doctor was available for 7033 attempted intubations. Non-anaesthetists carried out 4394 attempted intubations and failed to intubate in 41 (0.9%), whilst

anaesthetists attempted to intubate 2587 and failed in 11 (0.4%)- a difference which was statistically significant (p= 0.02). A new standard operating procedure was introduced in May 2012 and no failed intubations have occurred since – this difference (success rate before and after introduction) was not statistically significant (p=0.17). Forty-one out of 186 doctors (22%) had at least one failed intubation. One hundred and forty-five (78%) had no failed intubations. Among the 22% with documented failed intubation, the mean failure rate was 3.3% compared with 0.7% for the whole cohort. Six doctors had failure rates of > 5% and one had a failure rate of > 10% (11%).

The mechanisms of injury for patients who required surgical airway are shown below in table 3.6. The most common mechanism of injury resulting in a surgical airway was road traffic collision; 29 patients required this intervention. Seventeen of these 29 patients (63%) had a primary surgical airway; of these 9 patients were trapped. Two other patients who were trapped after falling under a train also required primary surgical airways. Twenty-one patients had a surgical airway following burns. Seventeen patients with severe injuries, commonly to the head and neck required surgical airways. Hanging was the mechanism of injury for eight patients.

Overall there were 18 survivors (20%); outcome data was unavailable for one patient. Twenty-nine patients were in traumatic cardiac arrest at the time of having a surgical airway; all died.

Table 3.6 Mechanism or type of injury in patients who received a surgical airway

Mechanism of injury	Number of patients, n (%)	Primary procedure(n)	Rescue procedure (n)	Unknown
Burns	21 (23.1)	9	12	0
RTC	29 (31.9)	17	10	2
Hanging	8 (8.8)	2	6	0
Head / facial injuries	8 (8.8)	1	7	0
Fall from height	6 (6.6)	2	3	1
Fall under train	3 (3.3)	3	0	0
Multiple injuries	9 (9.9)	6	3	0
Penetrating	7 (7.7)	5	2	0
Total	**91 (100)**	**45**	**43**	

3.4.4 DISCUSSION - ADULT INTUBATION

This study reports the largest series of physician pre-hospital intubations to data (217) and triples the physician data which was available when the metaanalysis on the subject reported in the last chapter was carried out. The reported success rate (99.3%) is in keeping with other smaller published series where the pooled median intubation success rate was 99.1% (217). In addition the rescue airway techniques had 100% success rates. The introduction of supraglottic airways has resulted in a proportion of rescue interventions carried out without surgical airway. Non-anaesthetists were twice as likely to have to perform a rescue airway intervention than anaesthetists and this difference was statistically significant. The model of emergency physicians and anaesthetists in our system fits the model of ‘competent’ and ‘expert’ intubators recently defined by Breckwoldt (218). This model defines ‘competent’ and ‘expert’ by the number of intubations carried out in routine practice by different physicians. This observed difference may be useful in targeting training and in the development of SOPs. Since the rate of failed intubation is low it is not possible to assess the

influence of new SOPs on failed intubation and the 0% failure rate since the latest SOP introduction is not statistically different to the previous failure rate. The rate of intubation failure between individuals is interesting. The majority have no failures but among the whole doctor population failure rates are very variable (0-11%). Early identification of ‘outliers’ may be useful to target training and reduce intubation failure rates.

Emergency cricothyroidotomy, though infrequently performed, is an essential skill in the management of the difficult airway. Cases on real patients are infrequent and despite the fact that less than 100 cases are reported here this is the largest series described to date. As expected a significant proportion of surgical airways were performed on trapped patients, those with severe burns and severe head and neck injuries. Most were severely injured and this is reflected in the very high mortality rate. Patients who had surgical airways performed when in established TCA all died in this series. The rate of surgical airway reported here is considerably lower than that reported in smaller series (Table 3.7) where pre-hospital physicians performed surgical cricothyroidotomy in 3.1% of cases (range 0.1% - 7.7%) (219-222), and non-physicians performed them in 5.75% of patients (range 0.5% - 18.2%) (223). The difference in skill mix and experience that exists between pre-hospital providers is likely to contribute to the rate of failed intubations and higher cricothyroidotomy rates. Those services in which muscle relaxants are not used in advanced airway management protocols are also more likely to have fewer successful intubations and more surgical airways (217).

Surgical airways were successfully performed in 100% of patients using a standard surgical technique. In this study a ‘successful’ procedure is defined as

correct placement of a tracheal tube followed by adequate ventilation. End tidal carbon dioxide monitoring is routinely used in patients undergoing advanced airway management.

The majority of studies of physician-led pre-hospital services also report success rates of 100%. In almost all the patients in these studies, a standard surgical technique for cricothyroidotomy was used (221,222). Only one study of 1106 patients undergoing advanced airway management, reported successful use of needle cricothyroidotomy in a single patient following failed intubation (224). Another physician-led service reported a lower success rate of 90% when using either a standard surgical technique, or commercially available kits (using a Seldinger method). The standard surgical technique was found to be both quicker and more successful (225).

In keeping with my results, published cricothyroidotomy success rates do not necessarily translate into high survival rates. The available literature suggests an overall survival rate of 26.5% (222). The heterogeneity in case mix, injury severity scores, and level of emergency service personnel make it difficult to interpret survival rates with any confidence. As surgical airways are commonly used as a last resort for severely injured patients where conventional airway management has failed, it is unsurprising that the overall survival is low. In total, 20% of patients in this study survived to leave hospital. The survival rate in the primary and rescue groups were similar (22.2% and 18.6% respectively). Twenty-nine patients in traumatic cardiac arrest underwent surgical airways, all of whom died.

The method of performing a surgical airway may contribute to success and patient outcome. A standard surgical technique is widely reported to be more

successful than a needle approach, and this was confirmed in a recent meta-analysis (204). Surgical cricothyroidotomy success rates were higher than needle cricothyroidotomy success rates (90.5% vs. 65.8%). Other studies report success with a surgical technique following failed needle or cannula cricothyroidotomy (207,226). Studies comparing the different commercial cricothyroidotomy kits with a surgical technique also conclude that a surgical technique is likely to achieve a definitive airway in a faster time, with fewer complications (227-229). The limited evidence available strongly suggests that surgical cricothyroidotomy should be the technique of choice when faced with a 'can't intubate can't ventilate' scenario. The delay in obtaining a definitive airway, when a needle or cannula technique is initially attempted but fails, could well translate into an increase in morbidity and mortality (230).

This study has demonstrated a high intubation success rate and 100% rescue success rate in a physician-led trauma service. This considerably increases the available evidence in this area of pre-hospital emergency medicine and strengthens the case for high level airway management in this patient group. In addition the study suggests higher success rates in anaesthetists than emergency physicians and also documents considerable variation in the success rates of individual doctors. This has training implications. The success rate with a standard surgical approach to cricothyroidotomy adds to the evidence for this technique over less successful needles or commercial kit techniques.

Table 3.7 Pre-hospital cricothyroidotomy rates

Authors	Design	Healthcare Provider	Surgical airway, n (%)	Success rate (%)	Complication rate (%)	Survivors, n (%)
Miklus J Trauma 1989	R	Physicians	20 (3.8)	100	0	8 (40)
Spaite Ann Emerg Med 1990	R	Paramedics	16 (Unknown)	88	31	3 (19)
Cook J Air Med Transp 1991	R	Paramedics / nurses	68 (2)	100	4.4	21 (31)
Nugent Ann Emerg Med 1991	R	Nurses	55 (18.2)	96	15	15 (27)
Xeropotamos Injury 1993	R	Physicians	11 (7.7)	100	0	4 (37)
Boyle J Emerg Med 1993	R	Nurses	69 (10.6)	98.5	9	5 (7)
Jacobson J Trauma 1996	R	Paramedics	50 (9.8)	94	4	19 (38)
Fortune J Trauma 1997	R	Paramedics	56 (15)	88	14	15 (27)
Gerich J Trauma 1998	P	Physicians	8 (2.4)	100	0	1 (12.5)
Robinson Air Med J 2001	R	Paramedics / nurses	8 (0.5)	62.5	NS	NS
Bair J Emerg Med 2003	R	Nurses	22 (10.9)	100	54.5	NS
Marcolini Prehosp Emerg Care 2004	R	Paramedics	68	NS	NS	8 (12)
Timmermann Resuscitation 2006	P	Physicians	1 (0.1)	100	0	NS
McIntosh J Trauma 2008	R	Paramedics / nurses	17 (2.4)	100	12	7 (41)
Adams J Trauma 2008	P	Physicians / nurses / combat medics	17 (5.8)	94	24	NS
Germann Prehsop Emerg Care 2009	R	Paramedics / nurses	6 (1.6)	100	NS	NS
Bulger J Emerg Med 2002	R	Paramedics	Needle: 30 (1)	NS	NS	37
Leibovici Am J Emerg Med 1997	R	Physicians	Seldinger: 13 Surgical: 16	90	Seldinger: 23 Surgical: 0	45
Warner J Emerg Med 2009	P	Paramedics	Needle: 4 (3) Surgical: 11 (8.5)	Needle: 25 Surgical: 90	18	NS
Nakayama Ann Surg 1990	R	NS	2 (22) All needle	0	100	0

NS: Not Stated R = Retrospective P= Prospective

3.4.5 INTRODUCTION - PAEDIATRIC INTUBATION

Paediatric intubation success was examined separately to the study reported above. As discussed in section two, paediatric trauma has different mechanisms and demographics to adult trauma (231) and airway compromise is uncommon. Also because paediatric anaesthesia is increasingly only performed by paediatric anaesthetists there is a reluctance to perform pre-hospital anaesthesia unless absolutely necessary (158). A retrospective database study of paediatric trauma patients who had pre-hospital airway interventions was carried out to establish the intubation success rate. Some epidemiological data was also collected to establish the circumstances under which these uncommon situations arise.

3.4.6 METHODS - PAEDIATRIC INTUBATION

The study setting is described in Section 1.2. Standard data on patients attended by the service is prospectively recorded on a Microsoft ACCESS™ database by the attending pre-hospital physician. A retrospective database review was conducted on patients attended between 1 January 2000 and 31 October 2011. No additional data were collected for this study and no additional interventions carried out. The project was approved as a clinical service evaluation by the local R&D department.

Inclusion criteria were all patients attended by the service under the age of 16 years. Patient demographics and mechanism of injury were recorded. Mission reports (standardised proforma) of every case of pre-hospital anaesthesia and intubation were then evaluated to look for additional detail including

complications or failed intubations. Statistical analysis was performed in Microsoft Excel™ and STATA v10.

In keeping with the AAGBI guidelines, the LAA SOP emphasizes that the threshold for paediatric anaesthesia is higher than that for adult pre-hospital anaesthesia and only be conducted when absolutely necessary (158). Where possible, prior to performing paediatric anaesthesia, the decision is discussed with an on-call consultant. This is to discuss equivocal cases or to assist with determining risk/ benefit analysis where the risk is felt to be extremely high or the benefit to be limited. This aspect of clinical governance and oversight is felt to be desirable when on-scene conditions are especially challenging.

3.4.7 RESULTS

During the study period from January 1st 2000 – October 31st 2011 a total of 14,716 trauma patients were attended and 3509 (23.8%) received pre-hospital intubation. Of these 14,716, 1933 (13.1%) were children (<16 years of age). A total of 315 intubations (9% of the total pre-hospital intubations) were carried out on children accounting for 16.3% of paediatric patient attendances. Of these, 255 (81%) of the paediatric patients received an RSI and 60 (19%) **(**Figure 3.8**)** were intubated without anaesthesia. The intubation success rate was 99.7% (i.e. one failed intubation out of 315).

Demographics

Of the 1933 paediatric cases attended, 1333 (69%) were male. Fifty-seven (2.9%) of these children were under the age of 1 year. Of the children receiving pre-hospital intubation, 209 (66.3%) were male. The median age was 10 years. Three children (1%) were under the age of 1 year, 78 (24.8%) were aged 1-5

years, 77 (24.4%) were aged 6-10 years and 157 (49.8%) were aged 11–15 years (Figure 3.9).

Time of Day

Data on intubation times were available for 297 patients. The frequency of pre-hospital intubation was observed to vary with time of day. A peak occurred between the times of 12:00 to 14:00 and a second greater peak occurred between 15:00 to 18:00. Few paediatric intubations (15 in total) occurred after 22:00 (Figure 3.10).

Mechanism of Injury

All patients had a clearly identified mechanism of injury. Three hundred and nine sustained traumatic injuries and 6 patients turned out to not be victims of trauma. Table 3.8 shows the mechanism of injury for all paediatric patients who received a pre-hospital intubation. Blunt trauma accounted for the majority requiring intubation with road traffic crashes (RTC's) and 'falls from height' accounting for 60.5% (n=191) and 18.5% (n=58) respectively.

More detailed evaluation of children involved in RTC's demonstrated that the majority of these patients were either pedestrians struck by vehicles (73.3%) or pedal cyclists (12.6%). One child was the driver of a motor vehicle (Table 3.8).

Scene time

For paediatric attendances, median scene time for patients that did not receive intubation was 20 minutes (interquartile range 12-28min). For intubation without drugs (in near or actual cardiac arrest) the median scene time was 21.65 minutes (median 19.5, interquartile range 15.3 – 25;). The median scene time when RSI was delivered was 41.6 minutes (median 40, interquartile range 32 –

49). 74.9% of patients were delivered to hospital within 60 minutes of the arrival of the operational team.

Failed intubation

During the study period, 95 doctors rotated through the service. Caseload range was 1 - 12 paediatric intubations per doctor. Of the 315 patients who received a pre-hospital intubation, one patient was classified as a failed intubation and was intubated only after arrival in hospital. In all other cases, the trachea was successfully intubated within two attempts when RSI was performed. In this single case (a 3 year old, suffering a 'fall from height', in respiratory arrest upon the arrival of the operational team) the trachea was unable to be successfully intubated after 2 attempts. Following the standard operating procedure, bag-valve-mask assisted ventilation maintained oxygen saturation at 95% and the patient was transferred to a trauma centre without further attempts at laryngoscopy. Further difficulty was encountered with intubation by the in-hospital team and the patient subsequently died from her injuries. The overall success rate was 99.7% for paediatric pre-hospital intubation.

3.4.8 DISCUSSION - PAEDIATRIC INTUBATION

The results of this study demonstrate a 99.7% intubation success rate for paediatric pre-hospital intubation by physicians. This success rate compares very well with undifferentiated physician pre-hospital intubation success rates reported in a recent meta-analysis (217). Other studies report success rates between 56% and 95% for pre-hospital intubation of children performed by paramedics or doctors (196,232-234). The factors that may have contributed to a high intubation success rate may include: service experience; doctor seniority;

training and simulation; intubation threshold and the relative ease of intubation of most anatomically normal paediatric airways. In addition, nearly three quarters of children intubated were between the ages of 5 and 15 years old, the significant anatomical differences in the paediatric airway rapidly diminishing with advancing age.

The results also confirm that the demographic of children attended by our trauma service are predominantly males and in an older age range. They have usually been involved with blunt trauma most commonly road traffic collisions as pedestrians or falls from height. They tend to be involved in accidents in the daytime particularly after schools end in the afternoon. Trauma in very young children and at night is rare.

A safety guideline published by The Association of Anaesthetists of Great Britain and Ireland (AAGBI) recommends that pre-hospital anaesthesia in children should only be performed by a skilled, anaesthetic-trained practitioner, once simple airway manoeuvres and oxygen therapy have failed to provide a patent airway and adequate oxygenation (158). The guideline suggests that even in relatively advanced systems, the threshold for pre-hospital paediatric intubation and anaesthesia should be relatively high. However, it is likely that in a small number of patients intubation is required to provide and maintain a definitive airway and can be lifesaving in a critically injured child if delivered rapidly and safely (235). This study does confirm that paediatric airway compromise in major trauma patients is uncommon even in a targeted trauma service serving a large population. In a trauma service which attended approximately 1500 patients a year only 13.1% were children. Accordingly, the

proportion of children that required intubation accounted for less than ten per cent of total intubations delivered. This low rate may be due to a high threshold for paediatric intubation in this very young age group and/ or the fact that basic airway management in small children is usually straightforward with the procedure of RSI being deferred until the ‘safer’ in-hospital environment. This service serves a large population (up to 10 million) with one operational team and therefore has a large trauma throughput. However individual doctors may only be in post for six months and if they carry out an average 150 trauma missions in this period they might expect to attend approximately 20 children of which only 3 will require intubation. The previous experience and training in the system is likely to be important, since even in a high throughput system, one paediatric intubation a month per doctor is likely. Breckwoldt has recently commented on the improved pre-hospital intubation success rates of ‘expert’ intubators rather than ‘proficient’ intubators (218). Our doctors are, by the definitions used in this paper, a mixture of the two (emergency physicians meeting the experience levels of ‘proficient’ and anaesthetists ‘expert’). We cannot be sure which (if any) element of experience, training or standard operating procedure has contributed to our reported intubation success rate in children. Our approach to this and other complex on-scene interventions, which I believe contributes to success, is that interventions are made as reproducible as possible with few choices and practiced often both clinically and in the simulation environment. Examples of this are well defined team roles, limited choices of drugs and routine use of an intubating catheter. Further investigation of the benefits of individual parts of this pathway might better identify the most

important elements, though the low number of paediatric cases may require extrapolation from manikin or other (adult) cases.

Paediatric supraglottic airways were introduced into this system two thirds of the way through the study period. They have never been used but are present because this system and the AAGBI pre-hospital anaesthesia guidelines aim for the same standards of anaesthesia as practiced in the hospital emergency department. Paediatric supraglottic airways are always available in emergency department practice

A median scene time of 20 minutes increasing to 41 minutes when RSI is delivered is thought to be consistent with other services delivering pre-hospital RSI. It is of concern and requires more investigation. The questions that I would like to see answered on this topic (which would take a prolonged time to address because of low reported frequency) are:

- Does uncorrected airway compromise in injured children adversely effect outcome?
- Is the increased scene time due to pre-hospital anaesthesia or other interventions? Can it be safely reduced?
- What is the time to definitive care (i.e. does pre-hospital anaesthesia reduce ED time and time to theatre / CT where indicated).

3.4.9 STUDY LIMITATIONS - PAEDIATRIC INTUBATION

Limitations of this study are those of retrospective database studies. Results are dependent on accurate reporting by clinicians and complete database entry.

Complications not recorded by clinicians may have led to their underreporting. We do not have reliable information on the difficulties encountered or number of intubation attempts made in each case, only intubation success. Outcome data is not reliably recorded on the database and therefore the relationship between RSI/ intubation and outcome could not be explored in this paper.

Figure 3.8 Paediatric intubation

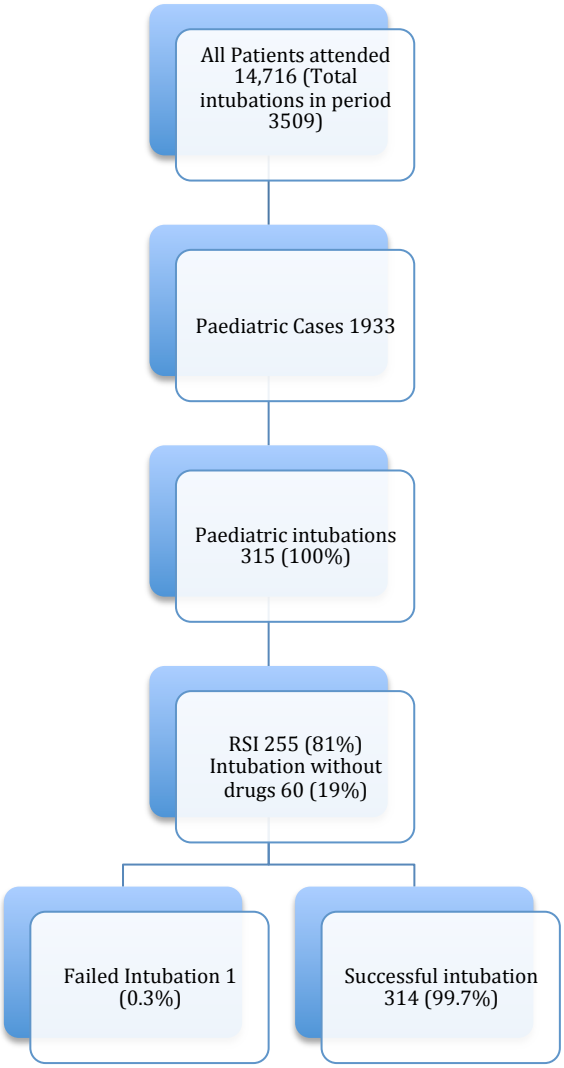


Table 3.8 Mechanism of injury for paediatric pre-hospital intubations

Mechanism of injury	<1 year		1-5 years		6-10 years		11 - 15 years		Total
	RSI	No Drugs	RSI	No Drugs	RSI	No Drugs	RSI	No Drugs	
Accident involving machinery	0	0	0	4.5% (n=1)	0	0	0	0	0.3% (n=1)
Animal incident	0	0	0	0	0	0	0.7% (n=1)	0	0.3% (n=1)
Burns	0	0	8.9% (n=5)	0	1.6% (n=1)	0	3.0% (n=4)	0	3.2% (n=10)
Drowning	0	0	3.5% (n=2)	27.3% (n=6)	3.2% (n=2)	6.7% (n=1)	0.7% (n=1)	14.3% (n=3)	4.8% (n=15)
Fall from height	0	100% (n=2)	44.6% (n=25)	4.5% (n=1)	16.1% (n=10)	13.3% (n=2)	11.1% (n=15)	14.3% (n=3)	18.5% (n=58)
Hanging	0	0	0	4.5% (n=1)	0	6.7% (n=1)	1.5% (n=2)	14.3% (n=3)	2.2% (n=7)
Penetrating trauma	0	0	1.7% (n=1)	4.5% (n=1)	0	13.3% (n=2)	4.4% (n=6)	14.3% (n=3)	4.1% (n=13)
Road traffic crash	0	0	37.5% (n=21)	50% (n=11)	79.0% (n=49)	46.7% (n=7)	70.4% (n=96)	33.3% (n=7)	60.5% (n=191)
Struck by object	100% (n=1)	0	1.7% (n=1)	0	0	6.7% (n=1)	3.0% (n=4)	0	2.2% (n=7)
Suffocation	0	0	0	4.5% (n=1)	0	0	3.0% (n=4)	0	1.6% (n=5)
Unarmed fight	0	0	0	0	0	0	0.7% (n=1)	0	0.3% (n=1)
Non – trauma	0	0	1.7% (n=1)	0	0	6.7% (n=1)	1.5% (n=2)	9.5% (n=2)	1.9% (n=6)
Total Number	**1**	**2**	**56**	**22**	**62**	**15**	**136**	**21**	**315**

Table 3.9 Designation of RTC children that received intubation

RTC – Patient Designation	Total Patients
Motorcyclist	3.1% (n=6)
Motorcycle pillion	1.6% (n=3)
Driver	0.5% (n=1)
Passenger	8.4% (n=16)
Pedal cyclist	12.6% (n=24)
Pedestrian	73.3% (n=140)
Unknown	0.5% (n=1)
Total	**100% (n=191)**

Figure 3.9 Frequency of pre-hospital intubation by age

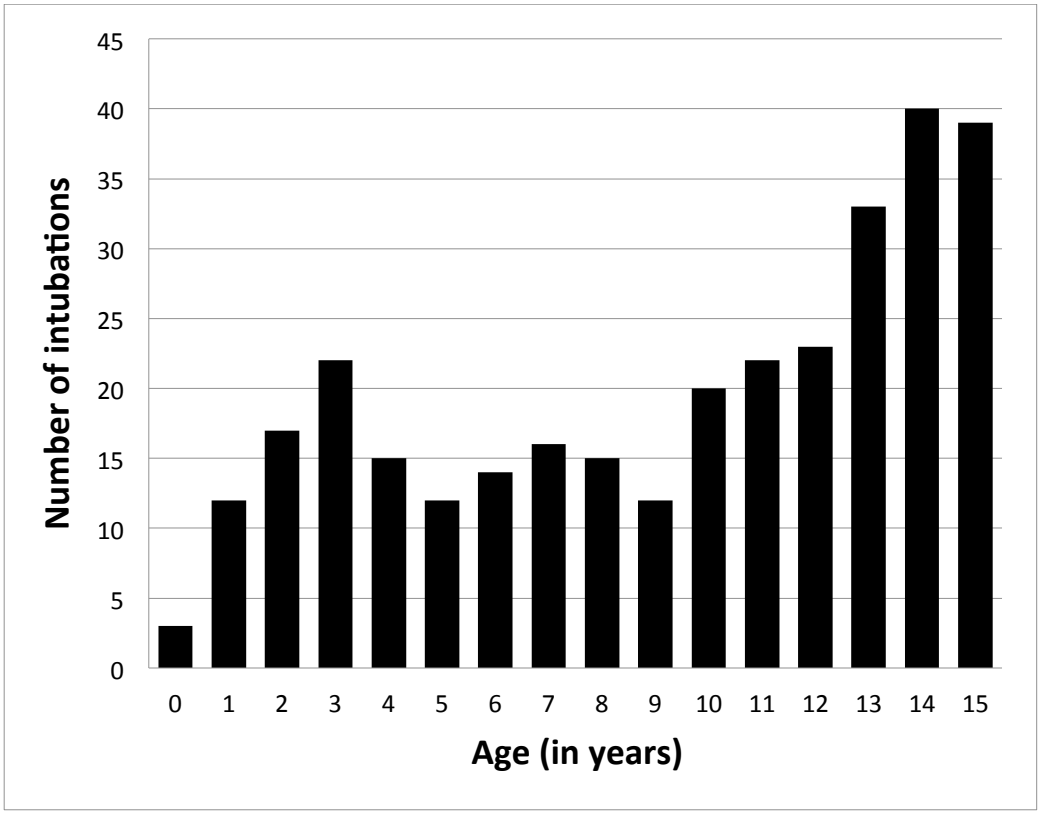
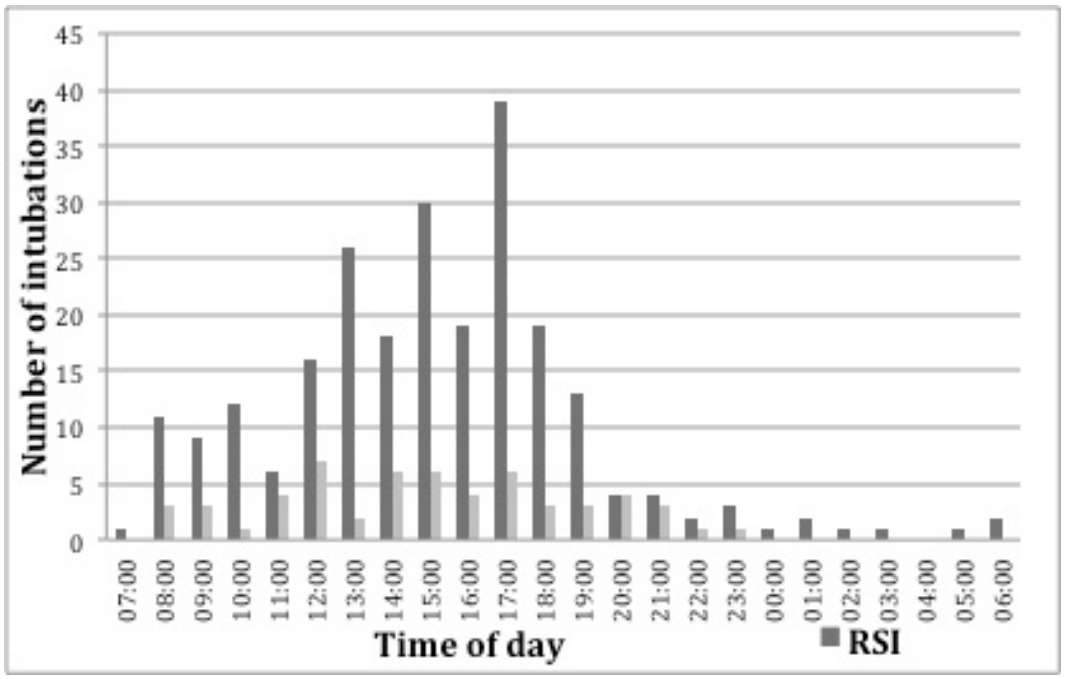


Figure 3.10 Paediatric intubation by time of day



Chapter 3.5

How can knowledge of the pre-hospital phase of airway management be improved?

3.5.1 INTRODUCTION

The limited quality and inconsistency of the available literature on advanced airway management makes it very difficult to generalise findings between EMS systems. I thus instigated the conduct of a formal consensus process to establish what key data need to be recorded by pre-hospital EMS services to improve the quality of data available for interpretation. The process aimed to produce a template that would allow pre-hospital organisations with different infrastructures to contribute information to the literature, which could be easily interpreted and compared. It would also allow the collaboration of pre-hospital organisations in different countries and systems to produce good quality uniform data and publications on specific areas of pre-hospital airway practice, particularly relating to patient safety and the reduction of adverse incidents. The process was therefore set up with a geographically widespread group of experts. This type of project has the potential to contribute to all elements of the Theoretical Model of Factors in Patient Outcome published by International Liaison Committee on Resuscitation, the so-called Utstein formula of survival (236). I chaired the consensus process. There were two trainees who recorded the discussions and the results were collected and written up by a group of four (the three above and one other). The process was funded by the Norwegian Air Ambulance (which has a formal research and development relationship with London's Air Ambulance).

3.5.2 METHODS

Methodology: The Modified Nominal Group Technique

Current clinical practice in pre-hospital care, emergency medicine and critical care is only evidence based to a degree. Evidence based practice is commonly derived from reports published in international registries and libraries, e.g. the Cochrane Controlled Trials Register (237), which primarily base their recommendations on randomized controlled trials. Although RCTs are considered the standard for medical research, ethical, legal and practical aspects limit the set up of RCT protocols in emergency care. Critical care patients are, by definition, rarely amenable to informed consent, and consequently there are a lack of RCT's in this field of medicine (238). Scientific reports in emergency care are predominantly based on quantitative observational cohort studies and animal studies. Observational studies are more easily conducted in an emergency care environment both in terms of ethical approval and interference with routine clinical activity. They also usually require much lower levels of funding. Observational studies are commonly based on data derived from dedicated registries, data retrospectively collected from medical records, or more rarely, data prospectively collected for the purpose of the study. The quality of data collected routinely for other purposes may be of variable quality (239). Even where the data quality is satisfactory, the fact that the data was defined and collected for other purposes can create uncontrolled bias and further influence both external and internal validity (240). Uncontrolled bias and lack of external validity can make interpretation of results challenging, and hinder systematic reviews (124,182,205).

This point is well illustrated by the 2010 ERC Guidelines for Cardiopulmonary

Resuscitation and Emergency Cardiovascular Care. Observational studies constitute a significant proportion of the reference list (28). This process ranks RCTs highly but they are uncommon, often inconclusive (non-significant), and rarely provide enough evidence on which to base a robust guideline. Thus, most of the recommendations are based on low levels of evidence.

A key challenge to researchers and clinicians has been to improve the quality of observational data collected in day-to-day practice. One method is to develop templates or standards for documenting and reporting data. A template or standard attempts to ensure that reported variables in specific patient groups, specific emergency medical conditions, and from specific interventions are consistent and reproducible. Such standardised variables with precise definitions may strengthen the quality of routinely collected data, and the validity of published reports, and further ease the analysis of reports in the production of systematic reviews. High quality, well defined, and internationally standardised data, collected on a regular basis, might enhance large international multi-centre studies and increase the quality of evidence.

Templates or standards for documenting and reporting data may be developed using qualitative methods, such as multidisciplinary expert panel consensus methods (241). This type of process has become an established method in the examination of the appropriateness of clinical interventions, to identify education and research priorities, and in studies on trauma-related preventable deaths (17,242). Expert panel assessments allow a combination of evidence-based knowledge, personal experience, and general insight in the characteristics of the patient cohort assessed or problem addressed. A critical step following the development of such templates for documenting and reporting is the

implementation of the agreed variables in existing registries, and the reliability and validity of the defined variables.

One of the first consensus based templates published for use in emergency care for uniform documenting and reporting of data was for out-of-hospital cardiac arrest. This was published in 1990 by a task force proceeding a conference held at Utstein Abbey, Stavanger, Norway (243). Since then, the Utstein Abbey has hosted many meetings that have resulted in similar “Utstein Style” guidelines. These meetings have achieved consensus based on variants, modifications or mixtures of the Delphi technique, the nominal group technique (NGT) and/or the consensus development conference method (244).To develop a template in pre-hospital airway management the modified NGT method was used.

The Delphi process has been widely used in health care research for defining priorities in education, clinical practice, organisation and planning. It is commonly based on three e-mail rounds where a large number of experts provide opinions on specific matters. The opinions are grouped and then re-circulated for ranking, and again summarised and then circulated for a re-ranking based on the individual experts insight in the group response.

The NGT process originates from efforts in large industrial companies aiming for a more structured decision-making tool (245). The NGT consensus methods gather a number of specially invited experts, commonly 10-15, for a structured meeting on a specific subject (241). The meeting is divided into separate rounds, where the experts propose, rate, discuss and re-rate on a list of items, variables or questions. The discussions are facilitated by an expert, or non-expert, highly familiar with the method. Consensus is reached by the end of the

meeting.

The modified nominal group technique

The modified NGT technique used combined the traditional Delphi process with the traditional NGT. It consisted of four steps:

Step 1

In the first step, experts were supplied with necessary background documents (existing templates, key papers on the subject, clinical guidelines) gathered by a co-ordinating project group. The expert was asked to return (by e-mail) proposals for inclusion and exclusion criteria, a set maximum number of core data variables in a prioritised order, and in addition, optional data variables regarded as important for template preparation. The proposed variables were divided into set variable subgroups. A maximum number of core variables were defined by the co-ordinating project group prior to each process, with the intention of keeping the expert panel focused on core data.

Step 2

The initial proposals were aggregated and systemized by the co-ordinating project group according to the frequency with which the experts had proposed the variable. The collated results were redistributed to the experts for comments and the experts were asked to rank the variables within each subgroup from one to ten. The results from step two formed the basis for the expert panel meeting (step three).

Step 3

The third step consisted of a consensus meeting in which the members of the expert panel, in groups and plenary sessions, discussed their views in a structured way and then made their conclusions. The consensus meeting

differed significantly in structure from the e-mail rounds. During the meeting, the discussion was open, letting interactions between the panel members influence the ranking and conclusions, also including novel variables if agreed upon. Overstepping the set maximum number of variables was allowed if agreed upon by the group.

Step 4

In the last step, based on the conclusions from the consensus meeting, the co-ordinating project group edited a final proposal for a template, on which the experts were allowed to comment by e-mail. To complete the process, a letter of agreement was signed by all expert panel members to enhance the implementation of the achieved template in the daily documentation of practice.

The experts

Physicians from Europe and North America who have contributed substantially to research, development of guidelines and/or are considered experts in the field of pre-hospital airway management were invited to join the panel. The panel consisted of clinicians most of whom are, or have been, directly involved in pre-hospital care. For participation in this process an international expert panel of fifteen was selected. The experts were identified by Google and PubMed searches on the subject, through personal networks of the co-ordinating project group, and by recommendations from already selected members. The expert panel was invited by e-mail and personal contact, and all asked to include information from their own experience or knowledge in the process. Invited experts who could not attend were asked to propose a substituting colleague. Three reminders were sent for non-responders.

The e-mail rounds

In the e-mail rounds the experts were supplied with an Excel™ spread sheet (© 2007 Microsoft Corporation, Redmond, USA) designed as a template for the proposals. The template was divided into category subgroups of data determined by the purpose of the template, i.e. system variables, patient variables and process variables (Appendix 2). Each variable required additional information on the exact data variable definition, possible data variable categories, and data variable source (i.e. hospital record, EMS record).
After each round, the experts returned their completed spreadsheets containing proposals to the co-ordinating project group.

The consensus meeting

In step three of the modified NGT, the expert panel gathered and agreed on inclusion and exclusion criteria and a core data set for the template during a 2-day meeting. Two experienced clinicians, familiar with the method, facilitated the meeting. In a first plenary section, the co-ordinating project group presented the proposed variables from step two, and the facilitators presented the set structure for the meeting. Then the experts were divided into two groups and discussed separately specific inclusion and exclusion criteria and variables for the proposed dataset. The groups subsequently presented their discussions in plenary sessions, where all variables were discussed, debated and agreed upon. On day two, the variables were given precise definitions and categorized in a plenary session. The project group did allow a few variables not to be accompanied by specific definitions during the meeting, authorising the co-ordinating project group to propose final definitions to be decided on during step 4 of the consensus process.

Limitations

There are limitations to this method. The choice of experts was partly unstructured and did not fully guarantee a representative selection of experts within all subfields of the subject at hand. This potentially leads to the omission of vital competences and important variables being missed. The process is vulnerable to collective group ignorance, not least caused by the risk of dominant expert panel members. The process does not test or check the true feasibility of the template, or the validity and reliability of each variable, but more mirrors the collective conviction of the expert panel.

Data point definitions

The data variables needed to be clearly defined to prevent misinterpretation, and to be simple to register and integrate well into existing databases and registries. It has been suggested that to achieve this a data variable dictionary should contain information on “data point number”, “data point name”, “descriptive field name”, “type of data”, “data point category/ value”, “definition of data point”, “source of data information” and “coding guidance” (83). The definitions used in the template are adapted to and in some cases based on ‘The Utstein template for uniform reporting of data following major trauma’ (83) and ‘Recommended guidelines for reporting on emergency medical dispatch when conducting research in emergency medicine’ (246).

Core data variables

As with previous Utstein style templates (83,246), I differentiated between core and optional data variables. I chose to focus on the core data variables; those data variables that absolutely need to be collected. These were divided into three groups based on their relation to the intervention advanced airway

management: “System variables”, “Patient variables” and “Post intervention variables”.

System variables

The system variables accurately describe the system in which the advanced airway management is performed. There are major differences between EMS systems not only internationally but also within countries. The system variables indicate the key differences and allow for comparison of the effect system structure may have on outcome

Patient variables

Patient variables describe the condition of the patient before the intervention; specifically physiological variables or scoring systems that describe co-morbidity, severity of injury or illness or other factors that may influence patient outcome.

Post intervention variables

The post intervention variables describe the interventions or care process related to advanced airway management. It covers success or problems related to the procedure, intervention description and patient variables that can be influenced by the care process.

Specific data issues

Many EMS systems have difficulty obtaining in-hospital data e.g. mortality data, on patients treated in the pre-hospital phase to complete follow up or quality assurance of pre-hospital treatment. This is often due to medico-legal or data security issues and the patient can often be “lost to follow up” as soon as the EMS personnel hand over responsibility for the patient to the hospital. Also,

most EMS systems feed into several different hospital systems and follow up is therefore logistically difficult. The expert group therefore chose to focus on variables that can be collected directly from the EMS patient contact without reliance on in-hospital data. However, the expert panel recommended that EMS systems establish methods to track the patient course after pre-hospital treatment.

Many system variables are fixed for a particular EMS system and do not change between patients treated; they can be regarded as fixed within the system. The expert panels therefore suggest that these key variables be reported at regular intervals or when they are changed but not for each patient. These variables are not included in the core system variables, but described separately.

3.5.3 RESULTS

The expert panel agreed that inclusion criteria were any patient receiving advanced airway management, defined as the attempted insertion of an advanced airway adjunct or administration of ventilatory assistance. Further, the expert panel agreed that advanced airway management during inter-hospital transfer should be excluded. In total the expert panel agreed on 23 core data variables (Appendix 2).

Discussion of inclusion/exclusion criteria and core data variables

Inclusion criteria

The template should include all cases of advanced pre-hospital airway management, but the definition of this term is poorly defined. The focus of pre-hospital airway management has traditionally been on tracheal intubation (TI), but supraglottic airway devices (SAD) are increasingly popular in pre-hospital

airway management (156). In the opinion of the expert group any airway management beyond manual opening of the airway and the use of simple adjuncts like a Guedel airway should be understood as advanced airway management. This includes the use of SADs, tracheal tubes and surgical airway techniques. Also, the expert panel agreed that patients in need of ventilatory support generally require advanced airway management and should therefore also be included.

Exclusion criteria

The expert panel decided that the template should focus on patients treated during ‘primary’ missions; defined as missions where the patient is located outside a hospital with emergency care capabilities. In secondary missions, or inter-hospital transfers patients are often already intubated and on ventilatory support and airway management is rarely required. In the opinion of the expert panel these secondary transfer cases probably require a different set of variables to properly describe them and are outside the scope of this template.

Fixed system variables

This group of variables are regarded as fixed within the system and do not change between patients. These variables are meant to provide a picture of the population and area covered by the EMS system, but also provide some information on how the EMS system is organized. The variables need only be documented and reported once and revised if changes occur.

System variables

Much of the discussion regarding pre-hospital airway management relates to who should perform the procedures (188) and recent guidelines from

Scandinavia have taken a stand in the discussion (156). The expert panel therefore agreed that it was important to include the level of EMS provider involved in airway management as a core variable to document the significance of this on the patient outcome. The provider with the highest practical competence level is recorded rather than who actually performed the procedure. In the majority of cases this is likely to be the same person. Where this is not the case the panel found it most likely that the person with the highest competence takes responsibility for the procedure whether or not they actually performed it. Supervision seems to increase the success rate of airway management (247).

Some studies suggest that the use of devices other than the tracheal tube (TT), e.g. SADs, can improve survival (248,249). SADs are also important rescue devices where tracheal intubation (TI) fails (156,250). These devices can only be used when they are available on scene, and therefore, it was agreed that the *availability* of devices also needs to be recorded (this may be a 'fixed data point' in many systems). This would also explain why, for example, in a system that is not set up for TI, a TT was not chosen as the final airway.

The use of drugs to facilitate airway management has also been debated. There is good evidence that the success rate of TI is dependent on the use of sedatives and neuromuscular blockers (98,251). Drugs are sometimes also necessary to facilitate insertion of SADs. Since the availability of drugs is a key factor in the success of airway management the panel agreed that this is a core variable.

There may be a relationship between mode of transport from the scene and survival in the case of trauma patients. Some studies report an improved

survival rate in trauma patients transported by helicopter compared with those transported by ground (16,252,253). Others have demonstrated that transport by lay persons increases survival (254). To what extent the transport mode influences survival in relation to pre-hospital airway management is unclear, but it might influence airway management procedures performed during transport. Because of this the expert panel finds that main type of transport should be included as a core variable.

Shy et al have shown that survival following cardiac arrest improves when the time from patient collapse to intubation is shortened (255). It therefore seems mandatory that this time interval be recorded in the template. However, reported times of patient collapse are often unreliable and would produce unreliable data. The panel agreed that the closest alternative would be to record response time. Studies have shown that survival improves with shorter response times (256) and the time interval is also a core variable in the Utstein template for dispatch (246).

Patient variables

Co-morbidity represents an independent predictor of mortality after trauma (257-259) and is also useful in critically ill patients (260). The update of the Utstein template for uniform reporting of data following trauma (Utstein trauma template) (83) recommended the use the American Society of Anaesthesiologists Physical Status (ASA-PS) classification system. In trauma patients, ASA-PS is shown to be a strong predictor of outcome (261). Although this system is specifically designed for recording pre-existing co-morbidity in pre-operative patients it is easily understood and simple to use. Using similar logic (83,261), the expert panel found this scoring system appropriate for

classifying co-morbidity in those patients receiving pre-hospital airway management. However, the panel recognized that the ASA-PS is unfamiliar in most pre-hospital systems and therefore recommended that only the categories co-morbidity of “no” (=ASA-PS 1), “yes” (=ASA-PS 2-6) or “unknown” be recorded as core variables. At the same time the panel strongly recommended that the individual ASA-PS scores be recorded at least as optional data variables as soon as the ASA-PS score is familiar to the system. The panel also found it necessary to emphasize that the ASA-PS classification system only be used to categorize co-morbidity that exists before the current incident (261).

Age is shown to be an independent predictor of survival after trauma (257) and is an essential variable for predicting hospital mortality in critically ill patients (262). Following the argument of the Utstein trauma template (83) the expert panel recommended that the patients’ nominal age be reported as a continuous variable rounding down and that age under 1 year be reported in decimals. This is in accordance with the Utstein trauma template (83) and simplifies data handling in electronic databases although it requires the users to translate a 12-month interval into decimals.

To the knowledge of the expert group no studies have shown any association between gender and airway management outcome or complications. Gender is disputed as a predictor for outcome in critically ill or injured patients; some have found associations between age, gender and outcome in trauma populations (258,263,264). The panel however acknowledged that gender is universally reported as part of standard population data and agreed that it should be included as a core variable.

Most studies on outcome following pre-hospital airway management are based on trauma patient populations (205). The intention of the current template is however to include all patient groups receiving airway management in the pre-hospital scene because non-trauma patients make up a large proportion of patients receiving pre-hospital airway management in many European EMS systems. There are few data addressing the effect of pre-hospital endotracheal intubation on survival in non-trauma populations (205). The expert panel therefore recommended that patients must be identified as trauma or non-trauma to allow this question to be explored. To avoid misinterpretation of certain special cases the panel decided to include burns and strangulation in the blunt trauma group and drowning and asphyxia in the non-trauma group.
The indications for airway management and especially ETI have been classified in three groups: failure of airway maintenance or protection, failure of ventilation or oxygenation and expected clinical course (that will require early intubation) (265). Other more specific indications are established in some EMS services (266). The expert panel believed that it was critically important that the template includes the indication for airway intervention in the core variables and suggested a list of nine categories. This can hopefully provide better insight into which conditions benefit from pre-hospital airway management.
The expert panel found it most appropriate to record actual values (continuous data) of all physiological variables chosen for the core data set. Since the focus is not only trauma patients it would be inappropriate to record, for example, only Revised Trauma Score (RTS) (267) when recording of raw data can easily be translated into appropriate categories for different scoring systems or prediction models. Furthermore, in the case of airway management many physiological

variables represent the indications for airway intervention and markers of success or complications following intervention (268).

The panel recommended recording initial pre-intervention values (first EMS contact with patient) for systolic blood pressure (SBP), respiratory rate (RR), GCS (Glasgow Coma Score), heart rate (HR) and SpO_2.

RR, SBP and GCS are core elements of the RTS, which has been used for many years to predict the outcome of trauma patients. The use of these variables to predict outcome in pre-hospital non-trauma populations has not been studied to the knowledge of the panel, and it was therefore important to include them in this template for future exploration of their predictive power in mixed populations. In the Utstein trauma template (83) all of these variables are included as core variables and also reported as actual values. RR is a well-recognized indicator of respiratory distress and may predict the need for airway intervention and ventilatory support. Pre-hospital SBP is a good predictor of severe injury (269), and although it is not a direct indicator for the need to manage the airway, changes post airway intervention may indicate cardiovascular complications. Recording both pre- and post intervention SBP therefore seems warranted. The same argument is valid for recording both pre- and post-intervention HR; changes in HR, e.g. bradycardia can signal cardiovascular complications or be associated with desaturation following airway management (270,271) and should therefore be recorded before and after the intervention.

The pre-hospital GCS is a strong predictor of outcome in patients with traumatic brain injury (272). Many regard GCS scores below 9 as an indication for intubation (1), but patients with traumatic brain injury and higher scores may

also require intubation (266). The panel therefore found the recording of pre-intervention GCS to be essential.

Davis et al (273) have shown that intubation at SpO_2 values below 93% cause a higher incidence of subsequent desaturation and that severe hypoxia during TI is associated with increased mortality (175). Others have also documented that hypoxia is one of the more common complications following pre-hospital TI (270,271) and that it is useful to document SpO_2 during pre-hospital TI (274). The panel recommended that the initial pre-intervention SpO_2 is recorded and that it is also recorded whether the patient was receiving supplemental O_2.

Post intervention variables

Poorly controlled ventilation following TI in patients with traumatic brain injury may worsen outcome (175,275,276). There are currently few data available documenting the same effect in mixed pre-hospital trauma or non-trauma cases. Continuous monitoring of end tidal CO_2 reduces the risk of inadvertent hyperventilation (277) and should therefore be applied in all intubated and ventilated patients pre-hospital (156). End tidal CO_2 monitoring is also mandatory to confirm successful TI (156,158). The expert panel therefore recommended that the type of post-intervention ventilation be recorded and that end tidal CO_2 values immediately after the airway intervention and on arrival in hospital be recorded as core variables.

As discussed above, SBP and SpO_2 should be recorded pre-intervention. Both variables may also signify post-intervention complications (175,270,271) and should therefore be recorded after airway management. The panel recommends that both variables should also be recorded immediately after arrival in hospital to avoid the potential problems of acquiring in-hospital data.

The expert panel recommends that pre-hospital survival should be the primary outcome measure for pre-hospital airway management. Many studies on pre-hospital intervention suffer from the lack of good survival data beyond the pre-hospital phase. This is usually because of strict rules restricting access to confidential in-hospital patient data. A recent study by Wang et al (278) on outcome after pre-hospital intubation errors presents a novel way to link pre-hospital data with anonymous in-hospital data, but at the same time illustrates the difficulty of achieving good survival data. The panel recommends that only survival data available from the pre-hospital phase be recorded as core data with the variables dead or alive on arrival hospital or dead on scene. Mandatory recording of in hospital or 30 days mortality will inevitably result in some pre-hospital systems unable to record the dataset. In systems were survival data are available the panels recommends that 30 day survival status be collected as an optional data point (261).

Data show that multiple attempts of TI are associated with a higher rate of airway related complications (271,279). The same may be true for SADs and the most recent Scandinavian pre-hospital airway guidelines recommend a maximum of three attempts of SAD insertion (156). The panel therefore recommends that the total number of attempts of airway intervention be recorded, including TI and SAD attempts. To record attempts at TI specifically the panel decided to add the data variable “intubation success” which records if TI was successful on first attempt or after more than one attempt and if more than one rescuer was involved. In a study including 2833 patients receiving in-hospital emergency TIs outside the operating room, Mort (271) showed a significant increase in airway related complications with three or more TI

attempts. The panel agreed that it was sufficient to distinguish between one or more than one attempt.

Complications related to airway management are probably more common in the pre-hospital setting than the in-hospital setting due to the environmental, patient and system factors (280). One of the most severe complications reported is oesophageal misplacement of the TT (174,200,219,281) often with fatal outcome. Other complications like right main stem tracheal tube misplacement, desaturation, regurgitation and cardiovascular events are also reported (219,270,271) and can lead to increased morbidity or mortality (175). The expert panel recommends that complications or problems related to airway management that are recognized during the pre-hospital phase be recorded as core variables. The panel suggested seven variable categories allowing for further categories to be defined.

The use of sedatives and neuromuscular blockers is shown to improve success rate of pre-hospital TI (156,251,280,282). The recent SSAI guidelines recommend the use of sedatives and neuromuscular blocker to facilitate ETI success (156). Using SADs in patients with intact airway reflexes may also require sedation of the patient to some degree although there is no data supporting this in the pre-hospital arena. The expert panel recommended that use of drugs to facilitate airway management, including for the insertion of SADs, be recorded as a core variable.

Finally, the expert panel recommends documentation of the type of device used to successfully manage the airway, meaning the device in place when the airway is regarded as successfully managed outside the hospital or the device in place on arrival at the hospital.

3.5.4 DISCUSSION

In this process a new Utstein style template was developed for documentation and reporting of pre-hospital airway management. The expert panel reached a consensus on 23 core data variables (Appendix 2) that should be documented by any EMS service providing airway management in the pre-hospital setting. In addition a set of 19 optional data variables were discussed by the expert panel and are included in the template.

The template includes all cases of airway management where any advanced technique beyond manual airway opening and bag mask ventilation (BMV) is attempted. Further, the template includes all patient categories treated pre-hospital, not only trauma patients. These two premises are important. The increasing use of SADs in pre-hospital airway management makes it necessary to also document their use. Currently the use of such devices pre-hospital and impact on patient outcome is probably even less well documented than TI (156). In many EMS systems a significant proportion of the patients treated are non-trauma. Although the focus of most studies on pre-hospital airway management has been on trauma populations several studies demonstrate that non-trauma patients make up a significant proportion of those intubated outside hospital (196,283). Pre-hospital airway management in these patient groups is not well documented, except in cases of cardiac arrest where TI has not been shown to influence survival according to a recent Cochrane review (27). Including the entire population receiving airway management pre-hospital will hopefully give a better understanding of what patient categories can benefit from it.

The 19 optional data variables included in the template consist of variables where the expert panel did not agree that they were core variables or where the panel believed that not all EMS systems would be able to document them.

In the system group the panel agreed that the airway management experience of the provider should ideally be documented, but they could not agree on how this should be achieved. One suggestion made was to indicate how many intubations the provider has performed in total, but this was felt to be a likely cause of unreliable and biased data. There is data to support that a learning curve exists for TI (284), but no studies have been done documenting this in the pre-hospital arena. The suggestion was however left as an optional variable urging the systems to documents this.

The expert panel discussed the recording and documenting of actual time events during pre-hospital treatment. Scene times have been shown to influence survival in some studies (285,286), but there are many factors involved and the importance of scene time vs. advanced treatment in critically ill patients is still unclear (252,287). Transport times have however been found to influence outcome (252). The panel agreed that time events should be recorded to allow time intervals to be calculated, but because it was recognised that the represented EMS systems had significantly different methods of time event definition and recording time events were therefore included in the list of optional variables.

Since a high Body Mass Index seems to be related to a higher incidence of complication in airway management (288), the recording of weight and height were discussed, but the panel concluded that exact documentation of these parameters is difficult in the pre-hospital phase. The variables were however

included as optional for systems that have reliable means of recording these parameters.

Physiological variables are included in the core dataset, but a more extensive set of physiological variables was also discussed. Including a large set of variables to be recorded in the core data set could however discourage users and therefore only a limited number of variables were chosen as discussed above. A set of optional variables was suggested for systems that have the means to record physiological parameters more extensively and reliably.

The composition of core and optional data points was necessarily controversial. The dataset produced was a compromise between what should be collected and what is currently practical for pre-hospital systems to collect. The entire panel agreed for example that in-hospital outcome data is vital information but most also recognized that placing it in the template as mandatory would considerably reduce potential use of the template. It may be that in subsequent revisions all of this data may become accessible and recordable.

Implementing an Utstein style template is always challenging. In the case of this template all members of the expert panel have signed a letter of intention where they agree on recommending and working for implementing the core template in their systems. The experiences from these systems will form the basis of a second meeting of all experts to revise the template according to experiences with the first template and any additional new research.

I have successfully developed an Utstein style template for documenting and reporting pre-hospital airway management. The core data set of this template can be included in future studies on pre-hospital airway management to

produce comparable data across systems and patient populations. The template will be implemented in systems where the expert panel has influence.

CHAPTER 3.6 Is key data reported in existing publications?

3.6.1 INTRODUCTION

I stated earlier that the data in the existing literature was inconsistent and difficult to interpret and this was the basis for the consensus process described above. To confirm that this was in fact true in a systematic manner a review of relevant studies was performed and the variables defined in the Utstein process extracted from the data presented. The aim of this study was to determine the rate of described Utstein airway variables (28 core variables and 12 fixed-system variables) found in the available scientific publications on pre-hospital TI.

3.6.2 METHODS

Study eligibility criteria

I included original English language articles relating to pre-hospital TI in adult patients. Studies that investigated paediatric cohorts and studies that focused on surgical airways were excluded. Studies that compared TI to other airway devices were also excluded.

Identification and selection of studies: data extraction

A systematic search of Medline and EMBASE according to the PRISMA guidelines to identify all relevant studies published prior to September 1, 2009 was conducted (see appendix 2 for search strategy) (34). All records were converted into an EndNote bibliographic database (EndNote X1 © Thompson Reuters, UK). The titles and abstracts were examined for eligibility. The full texts of all potentially relevant studies were obtained, and two reviewers assessed whether each study met the eligibility criteria. The reference lists of

the included studies and a recent relevant Cochrane review were inspected to identify additional relevant studies (205).

Study characteristics

Information from the included studies was extracted according to the published template for uniform reporting of data regarding pre-hospital advanced airway management (24). Reported variables that matched the Utstein variables were regarded as identical, although definitions sometimes differed or remained unreported.

The data were analysed using the Statistical Package for the Social Sciences, v. 18.0 (SPSS, Inc., Chicago, IL. USA), and the distributions were reported as medians and inter-quartile ranges (IQR). As a systematic literature review, this study did not need ethical approval.

3.6.3 RESULTS

Literature search

A total of 1,070 records were identified in the initial search. Another six records were identified through other sources. Among these 1,076 records, 75 full-text original papers were assessed. Two of these were excluded from further analysis, one because of qualitative methodology and one being a preliminary report, leaving 73 studies for the final analysis (Appendix 3).

Characteristics of the included studies

The majority of the studies (59, 81%) were from North American EMS systems. Of these, 46 (78%) described services in which non-physicians conducted TI. In contrast 13 (87%) of the 15 non-North American EMS systems, physicians

performed the pre-hospital TI. Of the 47 non-physician-manned systems, 25 (53%) performed drug-assisted TI.

Sixty-five studies had applied an observational methodology (89%), of which 29 were conducted prospectively and 36 retrospectively (Appendix 3). I identified two randomised controlled trials (RCT) and six non-RCT interventional studies.

Core variables

None of the included studies presented the complete set of 28 variables recommended in the template. The maximum number of core variables reported in a single study was 21. The minimum number reported was two, whereas the median number of core variables reported from all the studies was 10 (IQR 8-12).

The most frequent reported core variable was "patient category", reported in 63 (86%) of the 73 studies (table 4). The least reported variable was "co-morbidity", reported in only 2 (3%) of 73 studies (table 4).

Fixed system variables.

Of the 12 fixed system variables, the maximum number reported in a single study was 11. The median number reported was five (IQR 4-8), and two studies did not report any of the recommended fixed system variables. The most frequently reported variable was "service mission type", which was reported in 52 (71%) of the 73 studies. The least frequently reported fixed system variable was "type of available ventilator", which was only reported in one paper (1%).

All the studies included in the review are listed, and the number of matching core variables and fixed system variables from each study are presented in Appendix 3.

3.6.4 DISCUSSION

This systematic literature review revealed that the core airway variables identified by the expert group are not well reported in relevant existing studies. Recommended core variables, such as "post interventional $ETCO_2$", "number of attempts at airway intervention" and "co-morbidity", which were considered to be highly associated with efficiency and outcome, were missing in the majority of publications. Fixed system variables were incompletely reported or absent in most of the included studies. The low number of reported core variables makes it difficult to compare different scientific reports, assess their validity, and extrapolate to other EMS systems.

Several studies have focused on the intricacy of implementing TI in the pre-hospital setting (289-291). As previously discussed TI represents a *complex intervention* that contains several separate but highly interacting components. Scientific studies on this subject are difficult to design and interpret because of tremendous variability in (and insufficient description of) operator experience, technique, and patient case-mix, making it difficult to understand or eliminate confounding factors (292,293). Furthermore, neither contemporary interventions nor pre-, per- or post-intervention factors highly likely to influence outcome are usually documented, analysed or adjusted for. Key in-hospital factors (likely to be concealed from the investigator) further confound the outcome analysis. This finding may explain why apparently similar studies present conflicting results and reach different conclusions. It is impossible to judge intubation success rate without knowing if drugs were used to facilitate intubation and this variable is critical to interpretation of relevant studies. However, only 19 (31%) of the 73 papers in this study reported the variable "Drugs for airway management

available on scene". Where the variable was reported the definition and extent of drug assistance varied. Some services had protocols based on administering a muscle relaxant only; some combined this with a small dose of a sedative or analgesic, whereas some administered a traditional RSI. The presence or absence of drug assistance and the availability and dose of specific agents are likely to influence the success rate of TI and the rate and severity of adverse events.

The majority of the included papers were based on observational studies, commonly referred to as low-quality evidence (294). In a complex intervention, a true association between a single *cause* (TI) and an *effect* (survival) is difficult to prove). The presented results are flawed by multiple confounding factors, and external validity is questionable. Even randomisation may fail to exclude the major confounders. This is demonstrated by Gausche et al. in one of the few randomised trials on pre-hospital TI (196). The investigators reported no additional effect on survival or neurological outcome when paramedics performed pre-hospital TI compared to traditional bag/valve/mask ventilation in critically ill paediatric patients. The study set out to analyse the effect of the intervention itself, but due to an "intention to treat protocol", the intervention group was heavily confounded (abstained intubation, repetitive attempts of intubation, or failed intubation). The study instead may demonstrate the effects of suboptimal provider competence and TI complications, and it illustrates the challenges of using traditional analytical techniques when assessing a complex intervention.

Several recent reviews have assessed the evidence of a pre-hospital TI effect (182,295) including a Cochrane review (205). They consistently conclude that

the available evidence is limited and weak. It has been suggested that the traditional method of systematic review is of limited use in the evaluation of a complex intervention (296). The lack of a standard definition of pre-hospital TI poses a significant challenge for systematic reviewers and readers of these reviews. With respect to the Cochrane review on pre-hospital TI (205), the number of studies located in our review illustrates that any strict inclusion criteria for a systematic review will exclude the majority of studies published because pre-hospital TI is often performed differently or described inadequately. It also questions the whole evidence base on which current practice is based. This systematic literature review of studies investigating TI in adults demonstrated that core data required for proper interpretation of results were frequently not recorded and reported. The inconsistent and imprecise reporting of data may be the explanation for the fact that, despite numerous published studies on this subject, there is an ongoing debate on if, when, how and by whom pre-hospital advanced airway management should be performed. Pre-hospital TI is a complex intervention, and terminology and study design must be improved to substantiate future evidence based clinical practice. To support this, there is a significant need for an international standard for documenting and reporting pre-hospital TI in severely ill and injured patients. The newly published template might be a first and important step in this direction.

3.6.4 STUDY LIMITATIONS

This study has assumed that the recommended Utstein airway core variables are actually relevant to reporting in each study. Some studies focus on particular aspects of pre-hospital TI intervention and may not need to report all the core variables from the template. Nonetheless, understanding the

correlations between the intervention and its outcomes presupposes that all the interacting factors are accounted for.

The Utstein airway template still requires validation. Not all the variables relevant to outcome may have been identified. It may also be the case that some relevant studies may not have been located during our database search. In the future, more homogenous reporting of studies pertaining to pre-hospital TI may reduce these limitations.

Chapter 3.6 Discussion – Pre-hospital airway management

3.6.1 DISCUSSION

This section of my thesis has contributed the following material to the complex and controversial subject of pre-hospital advanced airway management:

I have reviewed the subject and concluded that the available published data is heterogeneous and difficult to generalise to other EMS systems. With this in mind I examined the key subject of whether, in my own EMS, standard ambulance service airway interventions were successful in resolution of airway compromise in victims of trauma. Had this been the case then the provision of advanced airway management by physicians by services like mine would be of questionable benefit. The NCEPOD report published in the UK in 2007 (17) did suggest that at that time ambulance service interventions were often ineffective and the results of my study do suggest that there is a demand for advanced airway management which is not currently met by paramedic intervention. It also suggests that the move to discourage paramedic intubation without drugs is the correct one (197) and may prevent life threatening complications such as unrecognised oesophageal intubation.

The concept that training improves outcome is borne out by the meta analysis presented on intubation success rates. Increased training improved one quality indicator of advanced airway management – intubation success rates. However, even when extensive training is carried out, paramedics do not achieve the success rates of pre-hospital physicians. This does provide evidence to support the presence of physician- paramedic teams if they can successfully be dispatched to the small number of patients that require this level of intervention.

The available data on physician intubation in the literature are limited, and detailed analysis of intubation success confirmed that a mixed group of emergency physicians and anaesthetists can practice in the UK pre-hospital environment with good intubation success and a simple but effective rescue algorithm. It may be that rather than relying on the standard technique of RSI, which was developed for in-hospital use long before the introduction of supraglottic airways, safety can be improved by careful adaptation or modification of the technique. Examples might include careful ventilation while muscle relaxation takes place (297) to prevent hypoxaemia. Prospective data from my system has challenged some of the long held beliefs related to RSI including challenging the use of cricoid pressure where laryngoscopy view is difficult (298), demonstrating that airway contamination is commonly from blood rather than stomach contents and may be prevented by the early use of supraglottic devices (203). As recorded in chapter 3.4 the introduction of a long acting muscle relaxant rather than the traditional short acting suxamethonium has not had any obvious safety implications to date. If after careful evaluation these components are introduced into pre-hospital standard operating procedures the overall procedure may bear little resemblance to ‘standard’ RSI but has the potential to improve success and safety.

The material presented on the background of advanced airway management confirms that data is inconsistent and of variable quality. The last two studies in this section address the concept of uniform data collection. The consensus process produced a template for international data collection. To realistically achieve improvement in data collection the template attempted to build on core data in existing databases and where additional data fields were recommended

they were made as simple and non onerous to record as possible. There is some encouraging take up of this template and a prospective study using the data fields identified from 14 international services including my own finished data collection in May 2013. The AIRPORT study will be the largest prospective study of physician-delivered airway management of its kind and will hopefully identify key issues that need further investigation.

Section IV Discussion and summary of thesis findings

Chapter 4.1.1

Discussion and summary of thesis findings

This thesis set out to examine two contentious areas of trauma intervention in pre-hospital care. Traumatic cardiac arrest was a subject which, when this thesis was planned, was considered to be generally futile with inevitable poor outcome. I have questioned this approach and demonstrated that survival is indeed poor but not dissimilar to survival in out of hospital cardiac arrest generally (76). This conclusion is supported by smaller studies in the same period but is still questioned (72). My data on pre-hospital thoracotomy (146) demonstrated that some patients cannot wait until arrival in hospital for life saving interventions and that the introduction of critical care interventions can make a difference particularly in populations where the frequency of particular trauma mechanisms is rising (117).

Having looked carefully at survivors of traumatic cardiac arrest I have perhaps inadvertently redefined the 'futility' group as those patients who arrest from hypovolaemia. There are a number of practical early treatments available for this group of patients including early transfusion (299), REBOA (134) and system changes that move the patient to surgical intervention more quickly (118) which may improve outcome. The possibility of more innovative in hospital interventions such as extended preservation resuscitation (133) might well be possible in the pre-hospital phase of care (Personal communication Dr Samuel Tischermann). While innovation and the introduction of established interventions into pre-hospital care may improve outcome, the implementation of guidelines to standardise and improve the quality of existing care may have the same result. The TCA algorithm presented (300) is a patient focussed

simple guideline which takes a similar approach to TCA as the ERC guidelines take to medical cardiac arrest. It has been initially well received and I am considering methods of assessment of effectiveness in coming years in the services that have adopted it as a Standard Operating Procedure.

The subject of pre-hospital advanced airway management is highly contentious for different reasons. It has been practiced to different levels by different professional groups on different patient groups for many years with conflicting results. My initial conclusions from the existing literature were that there are a small number of trauma patients who have airway compromise on scene and, if they were in the emergency department, would have immediate RSI. The literature also strongly suggests that advanced airway management is often performed badly outside hospital and it is unclear whether this outweighs the potential benefits in some systems. Unfortunately the questions raised threaten the scope of practice of some professional groups and are sometimes seen as being raised by physicians (who are responsible for the bulk of publications on the subject) but comment on paramedics (who deliver the majority of interventions). Since the available studies are heterogeneous and often difficult to generalise to other EMS systems, I concentrated on establishing the demand and results of advanced airway management in one physician –led system. My initial study clearly demonstrated that after existing paramedic airway intervention a significant proportion of seriously injured patients with airway compromise are still compromised. It is not clear whether the interventions available are ineffective or whether they are not being applied properly but the result is inadequate management. Although data capture for all quality indicators of airway management are rarely in place, a meta analysis indicated

that using the quality marker of intubation success paramedics do not perform as well as physicians even when using muscle relaxant and after extensive training. The meta analysis did illustrate that the data on pre-hospital physician intubation is not extensive. My study on intubation success in my system dramatically increases the available data on the subject and confirms the findings of the meta analysis. The very high intubation success rates were also demonstrated in children (in much smaller numbers).

Both of the subject areas studied suffer from one problem in common: the lack of consistently reported data that can be used to understand the nature, magnitude and pros and cons of particular interventions. The majority of pre-hospital studies are retrospective database studies and acknowledged to provide relatively low quality evidence. Although an academic approach to this might be to call for randomised controlled trials in the unproven interventions in pre-hospital care it is highly unlikely that this will occur. A more practical approach is to support the improvement in data quality and consistency from different EMS systems and use this to inform the need for high quality controlled studies in key areas. The two consensus processes that have been described in this thesis have attempted to move this agenda forward. A third process based on the same modified nominal group technique which I co-chaired in 2010 (301) has influenced data collection in several EMS systems including my own and has been adopted in all of the helicopter emergency services in Finland, Hungary and Norway. The deficits in recording the key identified data points in existing studies (159) explains why it is so difficult to generalise the findings between EMS systems. There are many locally established data collection systems in European EMS and it would be very optimistic to expect large scale

adoption of the key variables of any consensus process. However, the presence of these published studies at least provides material for consideration when new data collection systems are put in place. National trauma databases such as the Trauma and Audit Research Network (TARN) in the UK have made significant advances in trauma data collection. Data submission is now mandatory for all hospitals receiving trauma patients and there is a limited collection of pre-hospital data. The system is by no means perfect and the TARN eligibility criteria miss some patients of interest (e.g. those who stay in hospital for less than three days) but it does appear that the data availability on which to base future practice is improving.

I have examined only some aspects of two problem areas of pre-hospital trauma practice. What has become clear to me in the past few years is that with imagination and resource almost any in-hospital intervention could be extended into the pre-hospital phase of care. The challenge in the future will be to determine (with routinely collected high quality data and targeted controlled studies) which on-scene interventions can influence survival and which merely delay transfer to definitive care.

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Section VI Appendices

Appendix 1: LAA pre-hospital anaesthesia Standard Operating Procedure

Pre-hospital Care Standard Operating Procedure

Pre-hospital Anaesthesia

REVIEW:	Dec 2013	
APPROVAL/ ADOPTED:	PHC Policy Board	
DISTRIBUTION:	PHC Doctors PHC Paramedics	
RELATED DOCUMENTS:	SOP –Scene Safety	
THIS DOCUMENT REFERS TO:	☑ PHC Clinical Practice PHC Non-clinical Practice PHC Operational Procedure	Ref: CP-8

Aims:

- Define indications for pre-hospital anaesthesia
- Describe the procedure for performing rapid sequence induction (RSI)
- Describe the procedure for failed intubation
- Define the training plan and final assessment for RSI

Background:

London HEMS personnel carry out just over one RSI a day. This equates to a cumulative service experience of approximately 6500 pre-hospital inductions over approximately 20 years of practice. Although the RSI 'rate' has remained fairly constant the number has increased as a result of increased call volume and the move to 24 hour working. This algorithm has been developed to be simple and safe. For many years the algorithm consisted of RSI and surgical airway for failed intubation. This led to a surgical airway rate of around 2% - approximately half of which followed failed intubation and half were performed as primary procedures (where intubation was not attempted). This compares well with emergency room surgical airway rates for severely injured patients. We have added alternatives in the latest algorithm after careful examination of our pre-hospital experience and because of developments in airway management and published literature on management of the difficult airway. However we still expect the vast majority of our patients with airway compromise to either be intubated or get a surgical airway. We mainly see two types of patients who require drug assisted intubation – those who can have a controlled procedure with a few minutes of preparation and a small group who require immediate intervention with little or no time for preparation. Training should prepare the pre-hospital team for either situation.

Basic information on the drugs that we use can be found in the resource file. Ketamine is used as an induction drug, rocuronium and suxamethonium as muscle relaxants and midazolam and morphine for sedation, maintenance and analgesia. Ketamine with midazolam is used for procedural sedation and analgesia. These particular drugs are

used because of their relative haemodynamic stability and their relatively wide therapeutic margin – a 10 or 20% overdose is unlikely to cause significant problems (which is relevant in a working environment where patient weight is usually estimated).

Pre-hospital Anaesthesia working group
This version of the Pre-hospital Anaesthesia SOP was developed with the help of the following individuals to whom we are grateful:

London's Air Ambulance:
Prof David Lockey Dr Gareth Davies Dr Anne Weaver Dr Gareth Grier Mr Graham Chalk

External Experts:
Dr Jerry Nolan Dr Tim Cook Prof Jonathan Benger Dr Juergen Klein Lt Col Rhys Thomas
Dr Mark Bloch

Policy:

Indications for RSI

1. Actual or impending airway compromise
2. Ventilatory failure
3. Unconsciousness
4. Humanitarian need
5. Injured patients who are unmanageable or severely agitated after head injury
6. Anticipated clinical course

The decision to anaesthetise patients should be made on the basis of an 'on-scene risk-benefit assessment' in every case i.e. in each specific situation, do the potential benefits of RSI outweigh the potential risks?

Choice of drugs for induction

We have demonstrated that a 'quick look assessment' often identifies the group of patients in which most difficult laryngoscopies are likely to be encountered. We have also identified that in a significant number of our patients induction without an opioid results in significant hypertension after induction.

Option1: Standard induction: fentanyl 3 micrograms/kg (estimated weight) followed by ketamine 2 mg/kg and rocuronium 1 mg/kg. (' 3:2:1')

Option 2: Anticipated difficult intubation: ketamine 2 mg / kg + suxamethonium 1.5 mg / kg. Rocuronium 0.6 mg/kg after tracheal intubation achieved.

In patients suspected to have severe hypovolaemia the dose of induction agent and Fentanyl need to be significantly reduced. 50% of the standard dose should be administered in the majority of these patients.

Intubation Algorithm

- Address scene safety issues before RSI is considered, as described in the scene safety SOP.
- Where possible establish 360 degrees of access to the patient before RSI. This may involve moving the patient to another part of the scene or onto an ambulance trolley. Even if the patient is in near or absolute cardiac arrest this may the first manoeuvre. Do not attempt intubation or RSI in confined or cramped conditions unless there is simply no alternative - it is preferable to perform this outside or on a trolley in an ambulance.

- Commence monitoring with the Propaq monitor. Remember the Nonin monitoring device provides a reserve SpO2 and end tidal CO2 monitoring capability. Standards of monitoring satisfy the recommendations of the Association of Anaesthetists for in-hospital anaesthesia.
- Preparation for RSI: Preparations should be automatic and absolutely standard. Optimise the first attempt at intubation. Always use a size 4 laryngoscope blade in adults and in children above the age of 12 years. The flight paramedic establishes monitoring and rapidly provides a standard, laid out 'kit dump' **[appendix 2]** of equipment. Before commencing induction the doctor and flight paramedic run **rapidly** through the 'challenge / response' RSI checklist. **[appendix 3].** There are two checklists – one for 'Urgent' RSI and one for 'Immediate' RSI.
- After administration of induction drug (+/- opiate) and muscle relaxant the patient is intubated and tube position is checked by the following: direct vision (tube seen passing through cords, 'Easi-Cap™' colourimetric CO2 detector / continuous sidestream CO_2 detection and auscultation in both axillae and over the stomach.
- Where an adequate view of the vocal cords cannot be obtained, carry out the '30 second' drills. They are named to indicate that they should be easily completed long before the blood of a normal pre-oxygenated patient starts to desaturate.

Pre RSI Sedation

- In agitated patients it may be necessary to use small amounts of sedation to facilitate pre-oxygenation. Titrate small doses (1- 2mg of midazolam) to effect. In patients who are obviously hypovolaemic and hypotensive, use even smaller doses.
- In non head-injured patients with severe limb trauma ketamine [20 -30 mgs titrated to effect] can be used.

Pre-oxygenation

- Preoxygenate all patients in order to increase the time to commencement of desaturation. The aim of pre-oxygenation is to replace the nitrogen in the lungs with oxygen thus maximising the available reservoir of oxygen.
  This is done by ensuring that the patient has a tight fitting face-mask with oxygen attached. A patent airway is essential: if necessary, use airway adjuncts (nasopharyngeal, oropharyngeal, manual airway manoeuvres).

  In patients with severe facial injuries, pre-oxygenate and induce anaesthesia in the most comfortable patient position that enables good airway maintenance.

  Patients with a high BMI achieve better pre-oxygenation in a slightly (15 degrees) head-up position (with cervical spine protection maintained) or in the sitting position.

Failed intubation

- The i-gel is the default device for ventilation following a failed intubation attempt. This device minimises gastric inflation and the risks of aspiration and is therefore preferable to bag-mask ventilation (BMV).
- If no further changes can be made to improve the chances of successful intubation at a further attempt then the options are to leave the i-gel in place for transport (if it is functioning well) or to consider a surgical airway if it is not. If anatomy / morphology of the neck suggest this will be difficult or the physician decides that the risks of surgical airway outweigh the possible benefits, the i-gel should be left in place.
- Rarely consideration should be given to allowing a patient to wake and spontaneously breathe during transfer. Cautious sedation with midazolam may

be required to maintain control of the situation. Since in our patient population anaesthesia is only indicated where absolutely necessary the vast majority of our patients are not suitable for this management pathway.

I-gel™ device

- Although we carry the I-gel™ as an alternative airway device we expect it to be used rarely and expect the majority of failed RSIs in our system to be rescued with a surgical airway.
- We have used it instead of a standard LMA™ because, even with adequate muscle relaxation, many of our patients require relatively high airway pressures. This device has been demonstrated to allow ventilation at higher airway pressures without leakage than the Classic LMA™.
- Information on use is in the resource file. The device is inserted until the black line reaches the teeth. It is then tested and tied in place. A size 4 I-gel™ is suitable for all but the very tallest patients.
- It is used in preference to bag-mask ventilation to prevent gastric inflation and an increased risk of aspiration. It may rarely be inserted blindly into trapped patients in whom access is severely limited and augmentation of ventilation required. If this situation resolves the airway compromise, small boluses of propofol may be used to transport the patient to hospital.

Surgical Cricothyroidotomy

- Remove the surgical airway equipment from its pouch when it is anticipated that an airway will be particularly difficult. For example:
    - Airway trauma
    - Difficult anatomy
    - Burns to face and neck precluding jaw movement
    - Possible airway burns
- The technique of surgical cricothyroidotomy we use is rapid, reliable and relatively easy. It addresses two problems that we have commonly seen in the pre-hospital environment which make some of the 'standard' techniques less appropriate. (The Difficult Airway Society now recommends a very similar technique). These are bleeding from the incision and loss of the incision into the airway before or during tube insertion. A scalpel blade is carefully inserted horizontally into the cricoid membrane using a "stab / rocking" technique. Leaving the blade in position, a tracheal hook is pushed into the incision and traction maintained. The scalpel blade is removed and (with counter traction on the tracheal hook) a 6.5 mm cuffed tracheal tube is inserted (over a lubricated intubating bougie if necessary) into the trachea. The cuff is inflated, tube position confirmed in the normal way and ventilation commenced. The tube is then fixed in position with a tie or Elastoplast. The whole procedure should take only around 30 seconds.

The Airtraq airway rescue device

A number of videolaryngoscopic devices are now readily available. Some are complex and others have unacceptable battery requirements. The Airtraq is disposable, easy to use and has an integrated battery. It has however been found to perform poorly in the presence of blood in the airway. This device should be used to assist intubation in patients who have had induction of anaesthesia and who can be oxygenated with bag-mask ventilation but not intubated with direct laryngoscopy.

Paediatrics

- Pre-hospital anaesthesia of small children is required only rarely. For many children the risks of pre-hospital RSI outweigh the potential benefits. Where airway compromise cannot be overcome with simple airway manoeuvres, the

risk-benefit equation may change and drug-assisted intubation may become appropriate. The experience of the pre-hospital team attending the child may also influence the risks and benefits.

- Equipment for paediatric intubation is kept in the 'paediatric intubation pack'. Drug dose calculators and Broslow tapes are available and, if the age of the child is known, drug doses should be calculated on the journey to scene.
- Standard paediatric laryngeal masks are carried as an airway rescue device. Needle cricothyroid equipment is carried for paediatric use but is difficult to use effectively on scene or during transfer.

The 'Kit-dump'

- Monitoring on –running on automatic setting at 3 minute intervals

- Spread out yellow disposable bag and lay out:
  - Laryngoscope [size 3 and 4 blade]
  - Bougie
  - Tracheal tube [cuff tested]
  - Circuit: Easicap, catheter mount, filter [side stream connected]. NB consider mainstream in older monitor.
  - 20 ml syringe
  - Alternative smaller tube [cuff tested].
  - Alternative laryngoscope [alternative blade size].
  - 2 x nasopharyngeal airways
  - 1 x oropharangeal airway

- Ensure availability of:
  - Bag-mask connected to O2 tubing.
  - Spare O2
  - Difficult airway kit [surgical cric./ surgical airway pouch]
  - McCoy blade
  - Spare drug roll
  - Airtraq device

- Place suction to the right hand side of the patient's head. The 'Yankauer' suction catheter must be tested.

The Standard checklist

The purpose of the talk through is to:

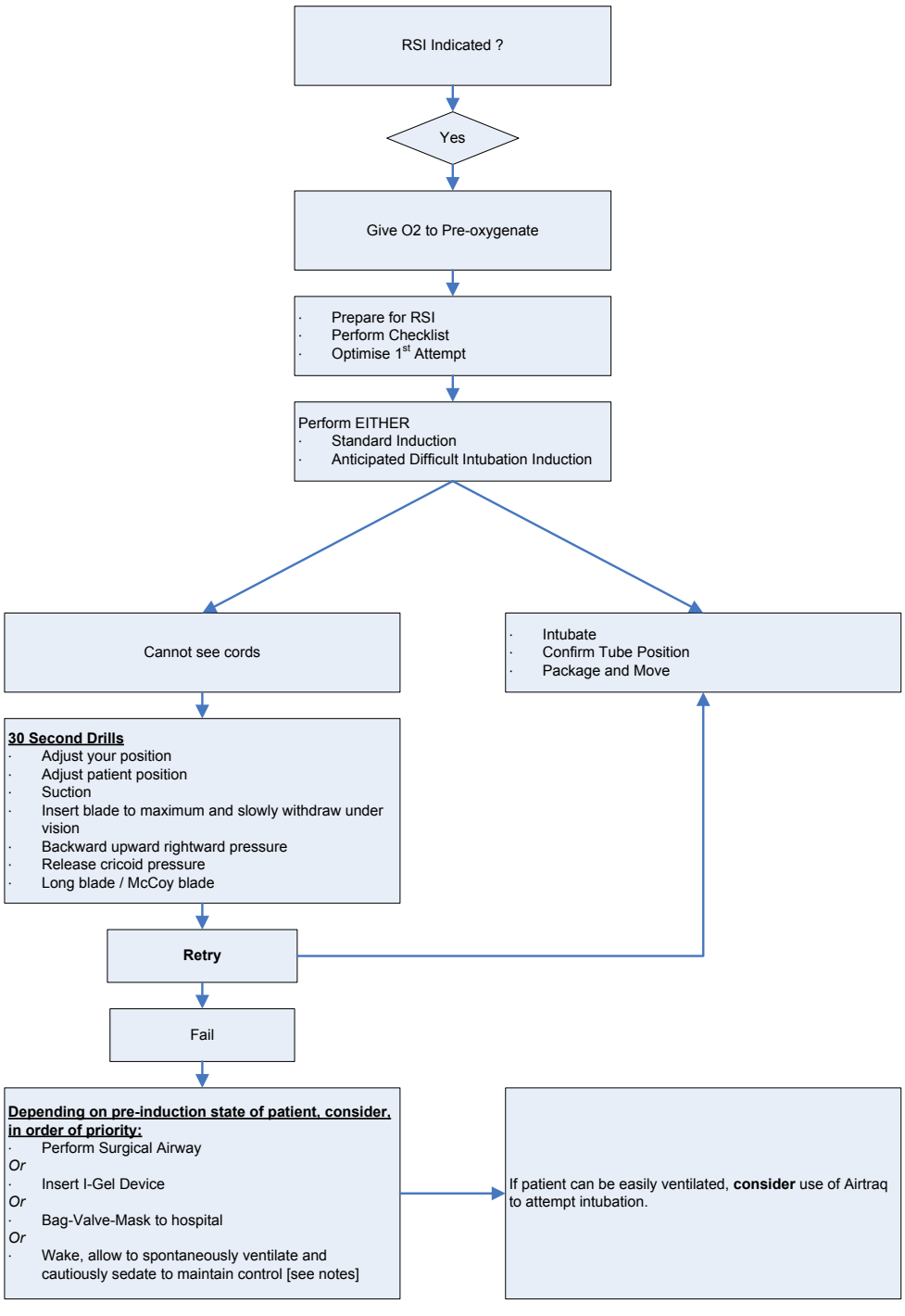
- Allow a defined period of preoxygenation
- Check that all the necessary equipment is present and working
- Ensure the position of the patient is ideal for intubating
- Reduce the chance of failed intubation

Address every step in the procedure in the order equipment will be used. This way no piece of equipment is missed out. While talking through, ensure the patient has a tightly applied reservoir mask and that the reservoir is moving with respiration.

Step in Talk through	Common problem	Benefits
Check baseline observations and cycle time for propaq.	Propaq slipped into manual mode and displaying old readings	
Check oxygen reservoir mask is tightly applied	No seal on mask, bag not working as reservoir, bag too cold and stiff to move in winter	Maximises pre-oxygenation
Check oxygen supply [where possible an E size cylinder]	Oxygen about to run out no reserves close at hand	Avoids hypoxia
Remove cervical collar		Jaw movement for laryngoscopy and cricoid / BURP
Check position of head and neck	Patient on scoop or floor with neck in extension, head in flexion, slight neck lat flexion	Maximises view.
Check drip is patent and easily flushed and not on side of BP cuff (or cuff down)	Drip not put in by you may never have been in or may have tissued	Avoids partial or non delivery of drugs, minimises chances of failed intubation
Check drugs and doses to be given. Check operator familiar with the doses to be given	Excess given though miscommunication [see sedation and analgesia SOP].	Avoids hypotension, ICP spikes or failed intubation through inadequate paralysis.
Check operator can perform cricoid pressure, is on left of patient & understands BURP	Most ambulance staff do not know how to perform either correctly. Operator usually on patients right and makes view worse with BULP	Better view at laryngoscopy Minimises chances of aspiration
Check laryngoscope functions and working spare is present	Weak battery, damaged bulb	Equipment presence Equipment failure
Check suction is present and working	Not present at scene Weak battery with poor function Wrong suction device	Equipment presence Equipment failure
Check bougie	In summer the bougie can become very soft	Equipment presence Equipment failure
Check tube is correct size and balloon does not leak	Tube's cuff balloon has small leak	Avoids need for tube change
Check presence of catheter mount, Easicap, filter and capnography		Ensures tracheal position of tube
Check valves in self inflating bag that reservoir and oxygen supply are attached		Equipment presence Equipment failure
Check tie		Equipment presence

London's Air Ambulance

Anaesthesia Algorithm



Appendix 2:

1. Search strategy for identification of relevant studies in Medline and EMBASE

2. The 28 core variables and fixed system variables for uniform reporting of data from advanced airway management in the field, identified by an international expert group

3. Fixed system variables for uniform reporting of data from advanced airway management in the field, identified by an international expert group

1. Search strategy for identification of relevant studies in Medline and EMBASE

Database	Search terms
	"keywords"
Medline	"Emergency Medical Services" AND "Intubation, endotracheal"
EMBASE	"emergency care" AND "intubation/ or respiratory tract intubation"
	"title"
Medline	"prehospital" AND "intubation"
Medline	"pre-hospital" AND "intubation"
Medline	"out-of-hospital" AND "intubation"
Medline	"prehospital" AND "RSI" OR "Rapid sequence induction"
Medline	"pre-hospital" AND "RSI" OR "Rapid sequence induction"
Medline	"out-of-hospital" AND "RSI" OR "Rapid sequence induction"
EMBASE	"prehospital" AND "intubation"
EMBASE	"pre-hospital" AND "intubation"
EMBASE	"out-of-hospital" AND "intubation"
EMBASE	"prehospital" AND "RSI" OR "Rapid sequence induction"
EMBASE	"pre-hospital" AND "RSI" OR "Rapid sequence induction"
EMBASE	"out-of-hospital" AND "RSI" OR "Rapid sequence induction"

2. The 28 core variables

Data variable name	Data variable categories or values	Definition of data variable
System variables		
Highest Level of EMS provider on scene	1 = EMS non-P 2 = EMS-P 3 = nurse 4 = physician 5 = unknown	Highest level of EMS provider on scene, excluding any non-EMS personnel (bystanders, family etc)

Airway device available on scene	1 = BMV 2 = Extraglottic device 3 = ETT 4 = Surgical airway 5 = none 6 = unknown	Airway devices available on scene and provider on-scene who knows how to use it
Drugs for airway management available on scene	1 = Sedatives 2 = NMBA 3 = Analgetics/ opioids 4 = local/ topic anaesthetic 5 = none	Drugs used for airway management, available on scene and someone competent to administer
Main type of transportation	1 = ground ambulance 2 = helicopter ambulance 3 = fixed-wing ambulance 4 = private or public vehicle 5 = walk-in 6 = police 7 = other 8 = not transported 9 = unknown	Main type of transportation vehicle (if multiple chose vehicle used for the majority of the transportation phase)
Response time	Minutes	Time from Emergency Medical Communication Centre operator initiates transmission of dispatch message to first resource/ unit time of arrival on scene of first unit as reported by first unit
Patient variables		
Co-morbidity	1 = No (ASA-PS = 1) 2 = Yes (ASA-PS = 2-6) 3 = unknown	ASA-PS definition 1 = A normal healthy patient 2 = A patient with mild systemic disease 3 = A patient with severe systemic disease 4 = A patient with severe systemic disease that is a constant threat to life 5 = A moribund patient who is not expected to survive without the operation 6 = A declared brain-dead patient whose organs are being removed for donor purposes
Age	YY or MM	Years, if patient < 2 years then months
Gender	1 = Female 2 = Male 3 = unknown	Patients gender
Patient category	1 = Blunt trauma (incl burns) 2 = Penetrating trauma 3 = Non trauma (incl drowning and asphyxia) 4 = unknown	Dominant reason for emergency treatment.
Indication for airway intervention	1 = Decreased level of consciousness 2 = Hypoxemia 3 = Ineffective ventilation	Dominating indication for airway intervention

	4 = Existing airway obstruction 5 = Impending airway obstruction 6 = Combative or uncooperative 7 = Relief of pain or distress 8 = Cardiopulmonary arrest 9 = other, specify	
RR initial	Number/ Not recorded	First value recorded by EMS provider on scene
SBP initial	Number/ Not recorded	First value recorded by EMS provider on scene
HR initial	Number/ Not recorded	First value recorded by EMS provider on scene
GCS initial (m/v/e)	Motor 1-6 Verbal 1-5 Eyes 1-4 Not recorded	First value recorded by EMS provider on scene See also GCS definitions
SpO2 initial, state: with or without suplemental O2	Number/ Not recorded 1 = Without suplemental O2 2 = With suplemental O2 3 = Unknown if suplemental O2	First value recorded by EMS provider on scene
Post intervention variables		
Post-intervention ventilation	1 = Spontaneous 2 = controlled 3 = mixed 4 = unknown	How is patient ventilated following airway management? If both spontaneous and controlled choose mixed.
Post-intervention SBP	Number/ Not recorded	First value recorded by EMS provider after finalised airway management
Post-intervention SpO2	Number/ Not recorded	First value recorded by EMS provider after finalised airway management
Post-intervention EtCO2	Number/ Not recorded	First value recorded by EMS provider after finalised airway management
Post-intervention SBP on arrival	Number/ Not recorded	First value recorded by EMS provider after patient arrives at hospital
Post-intervention SpO2 on arrival	Number/ Not recorded	First value recorded by EMS provider after patient arrives at hospital
Post-intervention EtCO2 on arrival	Number/ Not recorded	First value recorded by EMS provider after patient arrives at hospital
Survival status	1 = Dead on-scene or on arrival 2 = Alive on arival 3 = Unknown	Patient survival status: EMS treatment and on arrival hospital
Attempts at airway intervention	1 = one attempt 2 = multiple attempts 3 = earlier attempts 4 = unknown	Number of attempts at securing the airway with extraglottic device or ETI. Earlier attempts describe the situation where another EMS personnel has attempted to secure the airway before the current.
Complications	1 = ETT misplaced in oesophagus 2 = ETT misplaced in right	Problems and mechanical complications recognized on scene and caused by

	mainstem bronchus 3 = Teeth trauma 4 = Vomiting and/or aspiration 5 = hypoxia 6 = bradycardia 7 = hypotension 8 = other, define 9 = none recorded	airway management. Physiologic complications (5, 6 and 7) are regarded as such if they were not present before airway intervention and were recorded during or immediately after airway management. The following definitions are to be used: hypoxia: SpO2 < 90% bradycardia: pulse rate <60 bpm hypotension: SBP < 90
Drugs used to facilitate airway procedure	1 = Sedatives 2 = NMBA 3 = Analgetics/ opioids 4 = local/ topic anaesthetic 5 = none	Drugs used to facilitate the airway intervention. Select all that apply.
Intubation success	1 = success on first attempt 2 = success after more than one attempt and one rescuer 3 = success after more than one attempt and multiple rescuers 3 = not successful	Successful intubation defined as tube verified in the trachea. An intubation attempt is defined as attempted laryngoscopy with the intent to intubate
Device used in successful airway management	1 = Bag Mask Ventilation 2 = SAD 3 = Oral TI 4 = Nasal TI 5 = Surgical airway 6 = None 7 = Unknown	Device used to manage successful airway or device in place when patient is delivered at hospital/ED

ASA-PS - American Society of Anesthesiologists physical status EMS - Emergency Medical Service GCS - Glasgow Coma Score ED - Emergency Department EMS - Emergency Medical Service TT - Tracheal Tube NMBA - Neuro Muscular Blocking Agent SAD - Supraglottic airway device TI - Tracheal Intubation

3. Fixed system variables

Data variable name	Data variable categories or values	Definition of data variable
Population	Number	Population count in the primary response area of the EMS
Area	Number	Area in sq km or sq miles of primary response area of the EMS
Rural, urban, split	1 = Urban 2 = Rural 3 = Split	Urban area defined as: Data refer to 1 July of the year indicated and are presented in thousands"
Usual tiered response	Free text	Describe briefly
Time intervals collected	Free text	Describe briefly

Mission type	Free text	Describe briefly
Times available	Free text	Describe briefly
Established airway management protocols	Free text	Describe briefly
Airway management techniques available	Free text	Describe briefly
Describe type of training in airway management	Describe briefly	
Type of tracheal tube confirmation technique	1 = Auscultation 2 = Colorimetry 3 = Capnometry 4 = Capnography 5 = none	
Type of available ventilator	Free text	Describe briefly

EMS - emergency medical service.

Appendix 3: Frequency of Utstein variables in published studies

Aim of study, study design, TI provider, continent, number of the 28 Utstein core and 12 Utstein fixed system variables (%) reported in the 73 reviewed studies

Publication	Aim of study	Study design. (P=prospective, R=retrospective)	TI provider. PHY=Physician PAR=Paramedic/Nurse COM= Combined	Continent. NA=North-America, EUR=Europe, AUS=Australasia	No of Utstein core variables (%)	No of Utstein fixed system variables (%)
Adams, J Trauma. 2008; 64: 1548 –1554	To identify incidence of successful prehospital TI	Cohort (P)	PAR	NA	8 (29%)	5 (42%)
Adnet, Ann Emerg Med 1998; 32: 454-460	To establish the specific characteristics of performance of ETI in SAMU compared with those in paramedic systems.	Cohort (P)	PHY	EUR	13 (46%)	6 (50%)
Arbabi, J Trauma. 2004; 56: 1029 –1032	Early field intubation will improve survival compared with later ED intubation.	Cohort (R)	PAR	NA	8 (29%)	0 (0%)
Bair J Emerg Med 2005; 28: 403– 407	To characterize the tube verification methods employed by the intubating paramedics among patients with misplaced tracheal tubes.	Cohort (P)	PAR	NA	10 (36%)	4 (33%)
Bochicchio, J Trauma. 2003; 54: 307–311	Prospective evaluation of prehospital intubation improved outcome in adult trauma patients with nonlethal (death within 48 hours) traumatic brain injury.	Cohort (P)	PAR	NA	9 (32%)	5 (42%)
Bozeman, Prehosp Emerg Care 2006; 10: 8-13	Evaluation of lanyngoscopy conditions produced by two commonly used medication regimens in a multi aircraft air medical program.	Interventional crossover (P)	PAR	NA	19 (68%)	4 (33%)
Bradley, Ann Emerg Med 1998; 32: 26-32	Success and complication rates of prehospital tracheal intubation by rural EMT-Bs who underwent didactic and manikin training.	Non-randomised controlled trial with historic controls	PAR	NA	10 (36%)	7 (58%)
Bulger, J Trauma 2005; 58: 718 –724	To determine the effect of the use of NMBAs to facilitate prehospital intubation on outcome after TBI.	Cohort (P)	PAR	NA	12 (43%)	3 (25%)
Bushby, N Emerg Med Australas 2005; 17; 443–449	TRISS analysis to identify "unexpected survivors" suffering major thoracic trauma	Case review with comparative statisical analysis	PAR	AUS	10 (36%)	5 (42%)

Cantineau, JP Ann Fr Anesth Rëanim 1997: 16: 878-84	To investigate complications of PH ETI: Intubation difficulty, Cardiorespiratory consequences	Non-randomised comparative (P)	PHY	EUR	21 (75%)	9 (75%)
Christensen, EF BMJ 2003; 327: 533-534	To describe SI patients having PH ETI with or without RSI and access their chance of survival.	Cohort (R)	PHY	EUR	8 (29%)	6 (50%)
Cobas, MA Anesth Analg 2009; 109: 489–493	Investigation of relationship between intubation failure and mortality	Cohort (P)	PAR	NA	11 (39%)	8 (67%)
Colwell, Acad Emerg Med 2005; 12: 417-422	To determine success and complication rates associated with tracheal intubation in an urban emergency medical services (EMS) system.	Cohort (P)	PAR	NA	5 (18%)	8 (67%)
Cudnik, MT Prehosp Emerg Care 2008; 12: 459-466	To determine wether the transport distance modifies the relationship between OOH-ETI and mortality.	Cohort (R)	PAR	NA	13 (46%)	8 (67%)
Cudnik, Prehosp Emerg Care 2007; 11: 224-229	To determine if OOH-ETI increased total OOH time.	Cohort (R)	PAR	NA	14 (50%)	5 (42%)
Davis, J Trauma 2003; 55: 713-719	Impact of paramedic-administered neuromuscular blocking agents on airway management for all severely head-injured patients in a large, urban prehospital system.	Non-randomised controlled trial with historic controls	PAR	NA	14 (50%)	9 (75%)
Davis, J Trauma 2003; 54; 444-453	Impact of paramedic RSI on outcome in severely head-injured patients.	Non-randomised controlled trial with historic controls	PAR	NA	14 (50%)	11 (92%)
Davis, J Emerg Med 2005; 29: 391-397	Relationship between paramedic GCS scoring, head-injury severity, presence of factors related to the need for intubation such as hypoxia and aspiration, and eventual outcome.	Cohort (P)	PAR	NA	11 (39%)	1 (8%)
Davis, J Trauma 2005; 58; 933-939	To explore the relationship between paramedic ETI and outcome.	Cohort (R)	COM	NA	9 (32%)	6 (50%)
Davis, Prehosp Emerg Care 2006; 10: 356-362	Relationship between intubation success and perfusion status, GCS score, and initial end-tidal carbon dioxide value.	Cohort (P)	COM	NA	16 (57%)	8 (67%)

Davis, Prehosp Emerg Care 2008; 12: 46-51	To define a desaturation curve, when intubation attemps were made.	Cohort (P)	COM	NA	8 (29%)	7 (58%)
Denver MASG, Prehosp Emerg Care 2009; 13: 304-310	To determine paramedic intubation success and malposition rates in a large metropolitan EMS system.	Cohort (P)	PAR	NA	10 (36%)	8 (67%)
Eckstein, Trauma 2000; 48: 643-648	To determine the impact of prehospital ETI versus BVM on the outcomes of major trauma patients.	Cohort (R)	PAR	NA	8 (29%)	6 (50%)
Ellis, Emerg Med J 2007; 24: 139-141	To identify the incidence of intracranial pathology in a population of patients with trauma who had dropped only one or two points on their GCS. Difference in intracranial pathology in RSI/ non-RSI.	Cohort (R)	PHY	EUR	9 (32%)	1 (8%)
Fakhry, J Trauma 2006;	To formally review the procedural experience and outcomes of prehospital units with RSI in severely injured patients with high rates of TBI.	Cohort (R)	PAR	NA	17 (61%)	2 (17%)
Frankel, Am J Emerg Med 1997; 15: 630-632	To test the hypothesis that field OI in this urban setting with short transport times would have a favorable impact on both outcome variables.	Cohort (R)	PAR	NA	14 (50%)	8 (67%)
Gunning, Emerg Med J 2009; 26; 65-69	To describe the safety profile of emergency airway management when performed by a prehospital team consisting of a doctor and a paramedic.	Audit (P)	PHY	AUS	12 (43%)	4 (33%)
Helm, Br J Anaesth 2006; 96: 67–71	Evaluation in German HEMS system, the success rate of, and adverse factors influencing, pre-hospital ETI.	Cohort (P)	PHY	EUR	12 (43%)	6 (50%)
Jacoby, Ann Emerg Med 2006; 47: 525-530	To compare the success rate of etomidate and midazolam for sedative-facilitated intubation.	RCT	PAR	NA	17 (61%)	4 (33%)

Jemmett, Acad Emerg Med 2003; 10: 961-965	To determine the rate of unrecognised tracheal tube misplacement in a mixed urban and rural EMS setting.	Cohort (P)	PAR	NA	3 (11%)	8 (67%)
Jérémie, Eur J Emerg Med 2006, 13:148–155	To determine differences in clinical practices in three different SMURs with regard to the qualification of the operator so as to implement complementary training.	Observational comparativ (P)	PHY	EUR	12 (43%)	5 (42%)
Jones, Acad Emerg Med 2004; 11: 707-709	To determine the accuracy of ETI placement by ground paramedics in a large urban setting.	Cohort (P)	PAR	NA	4 (14%)	6 (50%)
Karch, Am J Emerg Med 1996; 14: 617-619	To determine whether the outcome in trauma patients intubated in the field was any different from that of patients with similar injuries intubated in hospital.	Cohort (R)	PAR	NA	5 (18%)	8 (67%)
Katz, Ann Emerg Med 2001; 37: 32-37	To determine the incidence of unrecognized, misplaced tracheal tubes inserted by paramedics.	Cohort (P)	PAR	NA	5 (18%)	8 (67%)
Klemen, Acta Anaesthesiol Scand 2006; 50: 1250-1254	To evaluate the impact of pre-hospital trauma care with ALS and RSI on the outcome in patients with severe traumatic brain injury (TBI).	Cohort (P)	PHY	EUR	17 (61%)	7 (58%)
Lockey, BMJ 2001; 323: 141	To investigate mortality in a trauma population who were intubated before reaching hospital without anaesthetic drugs.	Cohort (R)	COM	EUR	4 (14%)	4 (33%)
Mackay, Emerg Med J 2001; 18: 20-24	To study pre-hospital rapid sequence induction of anaesthesia to determine if there were differences in practice between anaesthetists and A&E physicians,	Cohort (R)	PHY	EUR	21 (75%)	8 (67%)
McIntosh, Prehosp Emerg Care 2008; 12: 438-442	To compare circumstances and success rates of air medical team intubations.	Chart review (R)	PAR	NA	8 (29%)	6 (50%)
Murray, J Trauma 2000; 49: 1065-1070	To evaluate the outcome of patients with severe head injury requiring pre-hospital intubation and to determine whether pre-hospital intubation is	Cohort (R)	PAR	NA	6 (21%)	2 (17%)

	associated with an improved outcome.					
Newton, J Trauma 2008; 64: 487-492	To establish the incidence of hypoxemia and hypotension during physician pre-hospital RSI.	Cohort (R)	PHY	EUR	11 (39%)	9 (75%)
Ochs, Ann Emerg Med 2002; 40: 159-167	To demonstrate the feasibility of paramedic use of RSI with focus on intubation success, physiological parameters, and complications.	Cohort (P)	PAR	NA	14 (50%)	11 (92%)
Osvalt, Am J Emerg Med 1992; 10: 511-514	To correlate the timing of intubation with the presenting of physiological parameters and clinical outcome to identify potential qualify assurance audit filters.	Cohort (R)	PAR	NA	14 (50%)	5 (42%)
Poste, Air Med J 2004; 23: 36-40	To explore the impact of air medical transport on patients undergoing paramedic RSI.	Non-randomised controlled trial with historic controls	PAR	NA	12 (43%)	7 (58%)
Rhee, Ann Emerg Med 1994; 23: 37-42	To compare the effectiveness of NMB-assisted oral intubation and NTI in a population of severely injured patients requiring endotracheal intubation in the field.	RCT	PAR	NA	11 (39%)	3 (25%)
Ruchholtz ,J Trauma 2002; 52: 879-886	To find out whether patients with severe thoracic trauma without respiratory insufficiency do or do not profit from pre-hospital intubation.	Cohort Comparative (P)	PHY	EUR	11 (39%)	3 (25%)
Sing, Am J Emerg Med 1998; 16: 598-602	Description of intubation mishaps, pulmonary complications, and outcome by aeromedical transport team using RSI for definitive airway control.	Cohort (R)	PAR	NA	16 (57%)	5 (42%)
Slagt, Air Med J 2004; 23: 36-37	To describe the patient population in which tracheal intubation was performed in the prehospital setting.	Chart review (R)	PHY	EUR	12 (43%)	5 (42%)
Sloane, J Emerg Med 2000; 19: 259-264	To compare RSI in the pre-hospital versus hospital setting in adult trauma patients requiring airway management to	Cohort (R) Comparative	COM	NA	8 (29%)	5 (42%)

	determine if differences exist in success rates, complications, and patient outcomes.					
Stiell,CMAJ 2008; 178: 1141-1152	Assessment of survival impact of systemwide introduction of pre-hospital ALS programs	Cohort Comparative (P)	PAR	NA	9 (32%)	7 (58%)
Sonday, Prehosp Disaster Med 2005;20: 324-326	To compare two induction agents in pre-hospital RSI	Chart review (R)	PAR	NA	11 (39%)	5 (42%)
Stockinger, J Trauma 2004; 56: 531-536	To evaluate the efficacy of ETI versus BVM in a trauma system.	Cohort Comparative (R)	PAR	NA	7 (25%)	4 (33%)
Swanson, Prehosp Emerg Care 2001; 5: 142-146	To describe the use of etomidate for RSI in the air medical environment.	Chart review (R)	COM	NA	12 (43%)	3 (25%)
Swanson, Air Med J 2002; 21: 28-31	To determine the impact of an education programme on prehospital ETI	Chart review (R)	PAR	NA	8 (29%)	3 (25%)
Swanson, Prehosp Emerg Care 2004; 8: 273-279	To compare etomidate with midazolam as sedative or induction agents for RSI in air medical transport system.	Chart review (R)	PAR	NA	12 (43%)	4 (33%)
Tam, Prehosp Emerg Care 2009; 13: 311-315	To examine the prehospital ETI practice and relative success rate when ETI is attempted within a Canadian EMS system.	Chart review (R)	PAR	NA	8 (29%)	8 (67%)
Timmermann, Anesth analg 2007; 104: 619-623	To determine the incidence of misplaced tracheal tubes when tracheal intubation performed by emergency physicians	Cohort (P)	PHY	EUR	11 (39%)	8 (67%)
Tracy, J Trauma 2006; 61: 1162-1165	To compare outcome of injured patients intubated in the field with patients intubated after arrival in the trauma centre.	Cohort (R) Comparative	PAR	NA	7 (25%)	0 (0%)
Ufberg, Am J Emerg Med 2005; 23: 379-382	To identify and compare the incidence of pulmonary aspiration of gastric contents between patients undergoing ETI in the PH setting and those intubated in the ED.	Cohort (P) Comparative	PAR	NA	3 (11%)	4 (33%)

Vadeboncoer, J Emerg Med 2006; 30: 131-136	To explore the timing of aspiration in patients with TBI.	Cohort (R) descriptive	PAR	NA	12 (43%)	2 (17%)
Wang, Prehosp Emerg Care 2001; 5: 10-18	To evaluate the impact of patient clinical status on prehospital ETI success rates.	Cohort (R) descriptive	PAR	NA	7 (25%)	10 (83%)
Wang, Prehosp Emerg Care 2001; 5: 134-141	To identify patients who could not be intubated in the field and to describe the methods subsequently used in the ED to manage the airway.	Cohort (R)	PAR	NA	8 (29%)	5 (42%)
Wang, Acad Emerg Med 2003; 10: 717-724	To identify factors associated with unsuccessful field ETI.	Cohort (R)	COM	NA	8 (29%)	4 (33%)
Wang, Prehosp Emerg Care 2004; 8: 1-9	To identify the factors associated with the use of prehospital DFI.	Cohort (R)	COM	NA	10 (36%)	4 (33%)
Wang, Ann Emerg Med 2004; 44: 439-450	To compare the effects of out-of-hospital ETI versus (ED) ETI on mortality and neurological and functional outcome after traumatic brain injury.	Cohort (R)	COM	NA	9 (32%)	1 (8%)
Wang, Acad Emerg Med 2006; 13: 372-377	To characterize the number of attempts required to accomplish out-of-hospital ETI.	Cohort (P)	COM	NA	3 (11%)	4 (33%)
Wang, Health Affairs 2006; 25: 501-509	To identify the prevalence of ETI errors and their association with patient and EMS system characteristics.	Cohort (P)	COM	NA	8 (29%)	5 (42%)
Wang, Ann Emerg Med 2007; 50: 246-252	To evaluate the effects of minimum tracheal intubation experience standards on the number and distribution of tracheal intubations.	Cohort (R)	COM	NA	2 (7%)	3 (25%)
Wang, Resuscitation 2009; 80: 50-55	To determine the association between out-of-hospital ETI errors and patient outcomes.	Cohort (P)	COM	NA	8 (29%)	5 (42%)
Warner, J Trauma 2007; 62: 1330-1338	To determine the incidence and impact of hyperventilation among a cohort of trauma patients undergoing prehospital ETI.	Cohort (P)	PAR	NA	11 (39%)	5 (42%)
Warner, J Emerg Med 2009; 36: 257-265	Comprehensive evaluation of large cohort of patients undergoing pre-hospital ETI with	Cohort (P)	PAR	NA	17 (57%)	8 (67%)

and without RSI.

Wayne, Prehosp Emerg Care 1999; 3: 107-109	To determine the safety and efficacy of succinylcholine, as an adjunct to tracheal intubation, administered by paramedics.	Chart review (R)	PAR	NA	12 (43%)	9 (75%)
Winchell, Arch Surg 1997; 132: 592-597	To measure the effect of prehospital ETI on outcome in patients with severe head injury.	Cohort (R)	PHY	NA	11 (39%)	5 (42%)
Wirtz, Prehosp Emerg Care 2007; 11: 213-218	To determine the incidence and impact of unrecognised pre-hospital ETI misplacement.	Cohort (P)	PAR	NA	4 (14%)	4 (33%)