Dental Age Assessment – Developing Standards for UK Subjects.

Thesis submitted by

Susan Parekh

BDS, MFDS, FDSRCS (Paed Dent), FHEA

For the degree of

Doctor of Philosophy

In the

Faculty of Biomedical Sciences

UCL

Division of Craniofacial Development

UCL Eastman Dental Institute,

256 Gray's Inn Road

London WC1X 8LD

UK

- 2011 -

Abstract

Dental Age Assessment (DAA) is used to estimate age when date of birth is uncertain. This thesis utilised radiographs archived at the Eastman Dental Hospital and King's College Dental Hospital. All teeth developing on the left side were assessed using an eight stage system (Demirjian 1973) and a twelve stage system (Haavikko 1970). The ages of attainment for each Tooth Development Stage (TDS) provided the Reference Data Set (RDS). Dental Age (DA) was calculated using weighted averages. DA estimates using the eight and twelve stage systems were compared, as were the effects of gender and ethnicity.

The relative distal root canal widths (RCW) of the 1st, 2nd and 3rd permanent molars were assessed using a five category system designed by the investigator. In addition ossification of the sternoclavicular joint (SCJ) was also assessed using a five stage system (Schmeling 2004). The stages and the categories were related to age. The improvement obtained by combining DA, RCW and SCJ data was explored.

A total of 2,622 subjects comprised the RDS with 45% male and 55% female, and an age range of 3 - 35 years. The main ethnic group was White (70%) followed by Black (13%), Mixed (5%) Asian (3%) and 'not recorded' for 9% of subjects. The mean difference between DA & CA was -0.15 years (SD 1.3) for males and -0.14 years (SD 1.4) for females respectively using 12 stages, and -0.14 years for both genders using 8 stages. The greater ease of use of the 8 stage system makes it preferable for DAA.

The combination of DA, SCJ & RCW showed that DA was the best predictor of an individual with teeth still developing. For subjects with no teeth still developing, SCJ can be used to estimate the age of an individual.

Declaration

I, Susan Parekh, 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. The following people contributed to the DAA database: Professor Graham Roberts, Dr Victoria Lucas, Ms Joy Teelana Boonpitaksathit, Julie Mitchell and Tricia Percival.

Acknowledgments

I would like to thank my supervisors for their support, advice, encouragement and for always being available throughout my study:

Tim Cole
BA, BPhil, MA, PhD, ScD.
Professor of Medical Statistics
Centre for Paediatric Epidemiology and Biostatistics
UCL Institute of Child Health
30 Guilford Street
London WC1N 1EH

Graham J Roberts MDS(Lond), PhD, MPhil, BDS, FDSRCS(Eng), ILTM, DipFHD (Apothecaries)
Locum Consultant in Paediatric Dentistry
Honorary Professor UCL
Honorary Professor KCL
King's College London Dental Institute
Camberwell
London, SE5 9RW

I would also like to thank Dr Paul Ashley and Dr David Moles for their helpful advice and comments, and Aviva Petrie for statistical advice, in particular for the meta-analysis approach.

Most importantly I would like to thank my family for their constant support and understanding.

Contents

List of tables

List of figures

List of abbreviations

BDJ	British Dental Journal
CA	Chronological Age
CT	Computerised Tomography
DA	Dental Age
DAA	Dental Age Assessment
DPT	Dental Panoramic Tomograph
EA	Estimated Age
EDH	Eastman Dental Hospital
FDI	Fedaire Dentaire Internationale
KCH	King's College Hospital
n-tds	number of subjects per tooth development stage
PI	Primary Investigator
RCW	Root Canal Width
RDS	Reference Data Set
SCJ	Sternoclavicular Joint
SQL	Structured Query Language
TDS	Tooth Development Stage
UASC	Unaccompanied Asylum Seeking Children
UCLH	University College London Hospital
UK	United Kingdom

1. Introduction

Age, or the time that a person has lived since birth, is an important cultural, religious and social phenomenon. Various stages of life are considered important milestones such as a child's first birthday, the time to start school and the right to vote. In criminal proceedings in the United Kingdom (UK), children under the age of ten years cannot be charged with a criminal offence (www.direct.gov.uk).

A precise date of birth is required to derive the chronological age of an individual. This is conventionally confirmed by the birth registration document. One in three developing countries has birth registration rates of less than 50%. Around 51 million children born in 2006 did not have their births registered and as a consequence, had no documentation to demonstrate their precise age. Birth registration represents the starting point for the recognition and protection of every child's fundamental right to identity and existence (www.unicef.org).

The problem arises when children or young adults migrate from countries where birth is not routinely recorded (due to poverty or lack of local resources), to countries where a confirmed record of date of birth is required for social, administrative and legal procedures. In addition, as children progress through school, further education and marriage, a formal birth certificate is often required as part of the administrative process.

This is of particular importance due to the increasing number of unaccompanied asylum seeking children (UASC), arriving in the United Kingdom (UK). In 2007, a total of 3,525 UASC aged 17 or under, applied for asylum in the UK. This was an increase of 2% from the 3,450 who applied in 2006. "When an asylum applicant claims to be a minor but his/her appearance strongly suggests that he/she is over 18, the Home Office's policy is to treat the applicant as an adult until there is credible documentary or other persuasive evidence to demonstrate the age claimed. This is known as an age disputed application. In 2007, a total of 1,915 applications were lodged with the Home Office for which the age was disputed". (www.homeoffice.gov.uk).

Growth is recognised as an indicator of health. The process of growth and development has been of considerable interest to physicians, anthropologists and dentists who have required guidance on normal development in order to correctly identify abnormalities. This has led to a variety of ways of assessing growth, one of which is the concept of maturity (Tanner 1975). When date of birth is uncertain, maturity markers may be used to estimate age.

Dental development has been shown to correlate with chronological age, and be less affected by malnutrition (Hotz et al. 1959; Lewis & Garn 1960; Green 1981; Melsen et al. 1986). The most commonly used method of assessing dental maturity is that of Demirjian (Demirjian et al. 1973). However, there are concerns with this method, as the reference group was French Canadian, and the possible effect of ethnicity was not considered. In addition, the Demirjian method does not include third permanent molars, making it unusable for young adults.

The main purpose of this study is to investigate dental development as a means of estimating age. In addition, the relationship of dental development to other methods of assessing maturity will be examined.

2. Review of the literature

2.1 Maturity markers

The maturity markers available for age estimation in children and adolescents include:

- Morphological Age.
- Skeletal Age:
  - Ossification of the hand-wrist
  - Ossification of the sternoclavicular joints
- Secondary sexual characteristics
- Psychological development.
- Dental Age (DA):
  - Tooth eruption
  - Tooth mineralization assessed from dental radiographs

These biological markers can be used separately or in combination to assess the physiological maturity of a growing child.

2.1.1 Morphological Age

Height was used to assess growth and maturity of an individual and was historically used for age estimation (Horner 1834). An individual's height is mainly determined by their gender, parents' height, and ethnicity. For example the average height in the Philippines for men is 163.5 cm and 151.7 cm for women (www.fnri.dost.gov.ph), compared to 184.3 cm for men and 169.9 cm for women in the Netherlands (www.statline.cbs.nl). This indicates the influence of ethnicity on age estimation. In addition, environmental factors such as malnutrition can affect height, especially if they occur during a growth spurt (Liversidge 2008a).

2.1.2 Skeletal Age

Skeletal age gained prominence owing to the ease of use of radiographs of the hand and wrist, following the development of the Greulich and Pyle Atlas (Greulich & Pyle 1959). The Atlas consisted of a series of 'typical' radiographs along a maturity scale, with the figure that was the closest match to the subject's radiograph used to determine the predicted age or maturity of the child. Another method involved assessing specific bones in the hand and wrist, and assigning developmental stages. Each of the developmental stages had a weighted score, which was summed for a given child to produce a maturity score which was then converted into a skeletal age (Tanner et al. 1983). These techniques are available for children and young adults up to the age of 18 years in boys, and 16 years in girls, when ossification of the bones is complete.

In contrast, the sternoclavicular joint starts to ossify at around 16 years in males and females, and reaches maturity at approximately 30 years for both. Therefore ossification of the sternoclavicular joint may be of use when determining whether a subject is under or over 18 years of age. However, the effect of malnutrition and hormone imbalance on skeletal development has been demonstrated by several authors (Tonge & McCance 1973; Melsen et al. 1986) who question the usefulness of skeletal age methods for age estimation.

2.1.3 Secondary sexual characteristics

During puberty, the secondary sexual characteristics appear. These changes are caused by hormonal effects, mainly testosterone and oestrogen which produce characteristic changes such as body hair, deepening of the voice in boys and onset of menarche in girls. Once sexual maturity has been completed, this is of limited use as it is not possible to say exactly when this has occurred, only that a person is fully mature. In addition, puberty maturation is unreliable as a means of estimating age, due to the wide age range, especially in relation to ethnicity (Butts & Seifer 2010). These changes are also subject to the effects of malnutrition and hormonal imbalance (Lewis & Garn 1960; Garn et al. 1965a), and again raising concerns about their suitability for age estimation.

2.1.4 Psychological maturity

Psychological maturity or intellectual development is often assessed in children and young adults using Piaget's Stages of Cognitive Development. This is based on defined stages of development related to brain growth:

- Sensory motor period (0-24 months)
- Preoperational period (2-7 years)
- Period of concrete operations (7-11 years)
- Period of formal operations (11-15 years)

(Myers RE 2009)

For each of these periods, it is expected that most children should be able to perform within the age range specified, for example children are capable of problem solving and think in a logical, organised manner during concrete operations. Intellectual development can be affected by abuse, trauma and low socioeconomic status (Elmer 1977). This questions the use of psychological maturity in age estimation, particularly in the group of interest, as most UASC fall into the above categories.

2.1.5 Dental Age

2.1.5.1 Tooth eruption

In 1836, English law stated that the limit at which a crime could not be legally imputed to anyone was 7 years of age. In criminal cases, where no direct proof of age was available, the medical practitioner was instructed to determine that "if the third molar (first permanent molar) had not protruded, there could be no hesitation in affirming the culprit had not passed his 7th year" (Thomson 1836).

The Factories Regulation Act of 1833 was passed to regulate the labour of children in mills and factories, stating that no child could be employed before the age of 9 years, and that hours of labour were restricted until 13 years of age. Birth registration, particularly among the poorer social classes, was frequently a matter of uncertainty; therefore age was certified by physical age and appearance (Horner 1834). Due to the variations in physical maturation of individuals, it was proposed by Sir Edwin Saunders in 1837 that the eruption of the permanent teeth be used to determine the ages of children from 7 to 14 years of age (Saunders 1837).

For many decades tooth eruption was the only criterion available for estimating age. This is unreliable as there is a wide age range for eruption of primary teeth (Hagg & Taranger 1986) and permanent teeth (Nystrom et al 2001). Other factors such as the space available, ankylosis and early or delayed extraction of primary teeth alter the normal eruption of the permanent successors. The advantage of using tooth eruption or tooth emergence, as an indicator of age is that the procedure is quick and non-invasive. The disadvantage is the long intervals between eruption of the teeth, particularly between eruption of the primary and permanent teeth, the considerable variability between individuals, the difficulty in reliably recording the precise moment the gingiva is pierced and the different definitions of tooth eruption employed by different investigators (Loevy & Goldberg 1999).

2.1.5.2 Tooth mineralization

The most widely used methods of attainment of the developmental stages of tooth growth as a means of estimating age, are based on assessment of the calcifying tooth which is divided into developmental stages discernible on dental radiographs. Histological and radiographic studies have indicated that the exact time of onset of cusp calcification is not determinable from a radiograph, as it is microscopic in size. However, once the cusp tissue has calcified, this minute center can be seen radiographically as an inverted cone (^). Therefore the approximate time of onset of dental calcification can be derived with the aid of radiographs (Gleiser & Hunt 1955).

Initially, extra-oral lateral oblique radiographs or cephalographs and intra-oral radiographs were required to view the developing permanent teeth. The introduction of Dental Panoramic Tomographs (DPT's) in 1954 allowed the visualisation of all the permanent teeth at one time, with reduced exposure to radiation (Tokuoka 1989).

Various methods have been devised (Table 2.1 shows a selection of methods) ranging from dividing tooth development into 22 stages (Schour & Massler 1941) to 3 stages (Garn et al. 1959). The claimed advantage of fewer stages is better reliability of inter-examiner agreement, but less precision of age estimation. In contrast, having more stages improves the accuracy of age estimation, but results in poorer repeatability (Thorson & Hagg 1991). The difficulty arises from determining the best compromise between accuracy and reliability for age estimation.

Authors	Year	Sample size	Number of stages
Schour and Massler	1941	Unknown	22
Gleiser and Hunt	1955	50	17
Garn et al.	1959	255	3
Hotz et al.	1959	298	11
Nolla	1960	50	10 (30*)
Moorees et al.	1963	345	14
Nanda and Chawla	1966	720	12
\Haavikko (modification of Gleiser and Hunt)	1970	1162	12
Johanson	1971	155	7
Liliequist and Lundberg	1971	287	8
Demirjian et al.	1973	2928	8
Gustafson and Koch	1974	41	4
Rosen (modification of Schour and Massler)	1981	760	19-22
Nortje	1983	500	8
Gat	1984	196	6
Kullman	1992	677	7
Mesotten et al. (modification of Gleiser and Hunt)	2002	1175	10
Sarnat	2003	693	7

Table 2.1 Number of tooth developmental stages by different authors. * Nolla stages can be divided into thirds, resulting in maximum of 30 individual stages.

It is believed that the greater number of developing teeth in younger children leads to greater accuracy of age estimation below the age of 10 years (Bolaños et al. 2003). This is because below this age there are more teeth developing and the duration of stages is shorter, therefore providing a more precise estimate (Hagg & Matsson 1985). This finding has been disputed by other authors, who have not found younger children can be more accurately predicted than older children (Maber et al. 2006). The best age estimation achievable is said to be within approximately 2 years, with a 95% confidence interval, due to the individual variation in tooth development (Mornstad et al 1995; Teivens et al. 1996).

Many authors have reported gender differences in tooth formation rates, with girls generally developing ahead of boys (Nolla 1960; Haavikko 1970; Demirjian & Levesque 1979; Hagg & Matsson 1985; Teivens et al. 1996; Bolaños et al. 2000). Others have noted differences between maxillary and mandibular tooth formation rates, with the mandibular teeth generally developing earlier, with the exception of third molars, where the maxillary teeth develop first, and interestingly, boys develop ahead of girls (Haavikko 1970; Mincer et al. 1993; Martin-de las et al. 2008).

A number of studies have shown that there is statistically no significant difference between development of the right and left side of the jaw (Nolla 1960; Haavikko 1970; Gat et al. 1984; Bolaños et al. 2000), whilst others have found that left-right symmetry between the maxilla and mandible for third permanent molars was 78% (Mincer et al. 1993). In general terms, left-right symmetry in development is very strong, although in clinical practice differences are occasionally seen.

Studies estimating dental age have used different methods and examiners, with varying sample size (52 – 3224), mixed or separate gender samples and unknown or poorly defined ethnic groups. The statistical analyses used have also varied, with some authors not indicating which methodology they have used, making comparison of studies difficult. A selection of studies looking at DAA are shown, highlighting the differences. (Table 2.2).

A further problem highlighted by Table 2.2 is the lack of information regarding ethnicity. Ethnicity has been shown to affect somatic growth, (Chinn et al. 1996; Sun et al. 2002; Saxena et al. 2004), and may influence dental development. All previous studies have involved retrospective analysis of radiographs; therefore information regarding ethnicity relied on dubious methods, such as appropriate sounding surnames (Teivens et al. 2001). Whilst this can be claimed to be reliable in homogenous communities, increasing globalisation has resulted in heterogeneous and ‘mixed-race’ populations, where relying on surnames is questionable.

Whilst the majority of studies have used the Demirjian technique (described in details in section 2.3.2), others have used other methods, and there is still no consensus as to which is the best approach. The Demirjian technique is easy to use and reproducible, but the limited number of stages, particularly of root development, may affect the accuracy of age estimation. This is due to the greater period of time between stages. For this reason, authors have modified the Demirjian method to incorporate extra stages (Solari and Abramovich 2002).

To address concerns regarding the use of subjective assessments, objective methods using linear measurements of the developing tooth with a digitiser attached to an x-ray viewer have been devised (Mörnstad et al. 1994; Kvaal et al. 1995; Liversidge et al. 2003; Cameriere et al. 2006). The results of some studies were promising, with one study claiming the mean difference between Chronological Age (CA) and DA of 0.12 days (Mörnstad et al. 1994, the method is described in detail in section 2.3.3). However, they did not give an indication of the time taken to do the assessments using linear measurements.

Authors	Year	Country	Method used	Sample size	Age range (years)	Males and females separate?	Ethnic origin of subjects	Statistics used
Nortjé	1983	South Africa	Nortjé	500	15 – 21	No	Coloured	*
Hagg et al	1985	Sweden	Demirjian, Liliequist & Lundberg, Gustafson & Koch	300	3.5–12.5	Yes	Unknown	*
Jaffe et al	1990	UK	Demirjian	52	7.4–17.5	No	Unknown	*
Staaf et al	1991	Sweden	Haavikko, Demirjian, Liliequist & Lundberg	541	5.5 – 15.5	Yes	Unknown	*
Mincer et al	1993	USA	Demirjian	823	14.2 – 24.9	Yes	White and Black	*
Mörnstad et al	1994	Sweden	Mörnstad	541	5.5 – 14.5	Yes	Swedish and northern Finnish	†
Mörnstad et al	1995	Sweden	Haavikko, Demirjian, Liliequist & Lundberg, Gustafson & Koch	197	5-12	Yes	Swedish	*
Nykanen et al	1998	Norway	Demirjian	261	5.4-12.7	Yes	Unknown	*
Koshy & Tandon	1998	India	Demirjian	184	5-15	Yes	South Indian origin	*
Liversidge	1999	UK	Demirjian	521	4-9	Yes	English & Bangladeshi	*
Tievens et al	2001	Sweden	Demirjian	485	2.6–17.2	Yes	Used typical Swedish surnames	‡

Willems et al	2001	Belgium	Modified Demirjian	2116	1.8-18.0	Yes	Belgian Caucasian	*
Willerhausen et al	2001	Germany	Kullman	1202	15-24	Yes	Surname	Not stated
Eid		Brasil	Demirjian	689	6.0 – 14.9	Yes	Brazilian	‡
McKenna et al	2002	Australia	Demirjian	615	4.9-16.9	Yes	Australian –born vs. non-Australian born	*
Mesotten et al	2002	Belgium	Gleiser and Hunt	1175	16-22	Yes	Caucasian	‡
Gunst et al	2003	Belgium	Köhler	2513	15.7 – 23.3	Yes	Caucasian	‡
Bolanos et al	2003	Spain	Nolla	525	3-14.83	Yes	Unknown	‡
Olze et al	2003	Japan and Germany	Demirjian	3031	12- 26	Yes	Japanese and German	*
Prieto et al	2005	Spain	Demirjian	1054	14 – 21	Yes	Spaniards	*
Leurs et al	2005	Holland	Demirjian	452	3-17	Yes	Surnames	*
Olze et al	2005	Germany	Gleiser & Hunt, Demirjian, Gustafson & Koch, Harris & Nortje, Kullman	420	12 - 25	No	German	Eta coefficient s
Maber et al	2006	UK	Haavikko, Demirjian Nolla, and Willems	946	3.0-16.99	Yes	Caucasian & Bangladeshi	*
Frucht et al	2006	Germany	Demirjian	1003	1-20	Yes	Surnames	‡
Blankenship et al	2007	US & Canada	Demirjian	1200	14-24.9	Yes	White and Black	Not stated

Martin-de las Heras et al	2008	Spain and Africa	Demirjian	572	14-22	Yes	Surnames	Not stated
Liversidge	2008	UK and South Africa	Moorrrees	3224	5 – 23+	Yes	Caucasian, Bangladeshi, Cape coloured & Black	Not stated
Tunc et al	2008	Turkey	Demirjian	900	4-12	Yes	Northern Turkish	‡
Cameriere et al	2008	Italy, Spain and Croatia	Demirjian, Willems and Cameriere	756	5-15	Yes	White	Not stated
Svanholt & Kjaer	2008	Denmark	Haavikko	244	7-14	Yes	Unknown	Not stated
Lee et al	2008	Korea	Demirjian	2706	1 -20	Yes	South Korean	*

Table 2.2 Comparison of different studies for Dental Age Assessment. [*] Mean and SD of age. † Multiple correlation coefficients (r) of age. ‡Indicates correlation coefficient squared (R2) of age

[*] Indicates mean difference and SD of age were used. † Indicates multiple correlation coefficients (r) of age were used. ‡ Indicates correlation coefficient squared (R^2) of age were used.

2.2 Comparison of maturity markers

Several studies have compared dental age based on discernible Tooth Developmental Stages (TDS), and indicated that they appear to be more reliable than other maturity markers, such as skeletal age, height and secondary sexual characteristics (Hotz & Weisshaupt 1959; Garn et al. 1965a; Garn et al. 1965b; Keller 1970; Tonge & McCance 1975; Green 1961; Melsen et al. 1986; Dahloff et al. 1989; Backstrom et al. 2000). The rate of tooth formation appears to be less affected by malnutrition and hormone imbalance than other parameters of maturity (Garn et al. 1965a, Anderson et al. 1975). This may be due to the fact that tooth development is largely genetically controlled (Garn et al. 1965b; Pelsmaekers et al 1997). Another difference between teeth and skeletal or secondary sexual maturation is the chronological regular rate of tooth formation, as opposed to the growth spurts experienced by the latter (Anderson et al. 1975; Liversidge 2008a).

The study by Lewis and Garn (1960) comparing several maturity markers, concluded that tooth formation proved less variable than menarche, tooth eruption, hand-wrist age or the appearance of ossification centres. The study sample consisted of 255 White, Ohio-born children who were part of a longitudinal study at the Fels Research Institiute, Ohio. Measurements of tooth calcification, somatic maturation, body size, osseous development and sexual maturation were made on a regular basis. Figure 2.1 shows that the coefficient of variability for apical closure was 7, compared with 8.5, 11, 15 and 19 for menarche, tooth eruption, hand-wrist age and ossification centres respectively. The authors concluded that tooth formation was closely correlated to CA, and believed that tooth formation afforded a more definitive and useful estimate of chronological age (CA) in children of ‘white’ ancestry (Lewis & Garn 1960).

Figure 2.1 Coefficients of variability of maturational factor (Lewis and Garn 1960)

2.3 Common methods of DAA

From Table 2.2 it can be seen that the two most common methods are Demirjian and Haavikko. These two methods and an objective method will now be described in further detail.

2.3.1 Haavikko

This method (1970) is based on a modified version of the tooth formation stages devised by Gleiser and Hunt in 1955. The study used cross-sectional data from DPT radiographs of 1162 Finnish children (615 boys and 547 girls) between the ages of 2 and 21 years. Twelve stages of tooth formation were assessed; six relating to crown formation and six relating to root formation, with Stage O allocated for appearance of a crypt of a tooth (Table 2.3). Separate illustrations were given for single rooted and molar teeth (Figure 2.2). Maxillary and mandibular permanent teeth were considered separately, with the results from the right and left sides of the jaw combined. Third permanent molars were included and no score was allocated for missing teeth.

Tooth Development Stage (TDS)	Number for Stage	Single Rooted Teeth and Multi Rooted Teeth
o	**01**	Crypt present, no calcification
C_i	**02**	Initial calcification
C_{co}	**03**	Coalescence of cusps
$Cr_{1/2}$	**04**	Crown ½ complete
$Cr_{3/4}$	**05**	Crown ¾ complete
Cr_c	**06**	Crown complete
R_i	**07**	Initial root formation
$R_{1/4}$	**08**	Root length ¼
$R_{1/2}$	**09**	Root length ½
$R_{3/4}$	**10**	Root length ¾
R_c	**11**	Root length complete
A_c	**12**	Apex closed

Table 2.3 Definition of Haavikko Stages of Development for Single Rooted and multi-rooted Teeth (Haavikko 1971).

Figure 2.2. Schematic drawings of Haavikko 12 stage system used to identify Tooth Development Stages (01 to 12).

For each child, the age and stage of each tooth was recorded, and median ages for each TDS in the whole sample were calculated, including stage Ac. Results for individual teeth were given with median ages and dispersions between the 90^{th} & 10^{th} percentiles for upper and lower teeth and boys and girls separately. To determine the age of a subject, the sum of the median ages per tooth stage were calculated and then divided by the total number of teeth to give the estimated age of a subject. However it does not give any indication of the range of values possible nor the variability of the sample, as 95% CI values were not given. Stage Ac was included, but no mention was made of how the upper age limit for each tooth was identified. In addition, the median age for stage Ri was not given, meaning it could not be used in the final analysis.

The author also devised a simplified system to investigate whether it was possible to make reliable estimates of tooth formation ages using selected teeth (Haavikko 1974). The correlation coefficients for the permanent mandibular second molar and first premolar were highly significant for all age groups. However, the high correlations were most likely attributable to the fact that the material for the simplified method was the same as the reference sample used for the estimates of mean age of the tooth formation stages. Therefore the high correlations were to be expected. This casts doubt on the validity of the simplified method.

2.3.2 Demirjian & Goldstein

The system devised by Demirjian, Goldstein and Tanner (1973) and later modified (Demirjian & Goldstein 1976) assessed the 7 left permanent mandibular teeth discernible, dividing each tooth into eight developmental stages, using detailed written criteria (Table 2.4) and illustrations (Figure 2.3). No stage was allocated for crypt formation.

TDS	**Single Rooted Teeth and Multi-Rooted Teeth [Descriptions]**
A	In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt in the form of an inverted cone or cones. There is no fusion of these calcified points.
B	Fusion of the calcified points forms one or several cusps, which unite to give a regularly outlined occlusal surface.
C	**a**. Enamel formation is complete at the occlusal surface. Its extension and convergence toward the cervical region is seen. **b**. The beginning of a dentine deposit is seen. **c**. The outline of the pulp shape has a curved shape at the occlusal border.
D	**a**. Crown formation is complete down to the cemento-enamel junction. **b**. The superior border of the pulp chamber in uniradicular teeth has a definite curved form, being concave towards the cervical region. The projection of the pulp horns, if present, gives an outline like an umbrella top. In molars, the pulp chamber has a trapezoid form. **c**. Beginning of root formation is seen in the form of a radiopaque spicule.
E	UNIRADICULAR TEETH **a**. The walls of the pulp chamber now form straight lines, whose continuity is broken by the presence of the pulp horn, which is larger than in the previous stage. **b**. The root development is still less than the crown. MULTIRADICULAR TEETH **a**. Initial formation of the radicular bifurcation is seen in the form of either a calcified point or a semilunar shape. **b**. The root length is still less than the crown height.
F	UNIRADICULAR TEETH **a**. The walls of the pulp chamber now form a more or less isosceles triangle. The apex ends in a funnel shape. **b**. root development is equal to or greater than the crown. MULTIRADICULAR TEETH **a**. The calcified region of the bifurcation has developed further down from its semilunar stage to give the roots a more definite and distinct outline, with funnel shaped endings. **b**. The root length is equal to or greater than the crown height.
G	**a**. The walls of the root canals are now parallel (distal root of molars). **b**. The apical ends of the root canals are still partially open.
H	**a**. The apical end of the root canal is completely closed (distal root in molars) **b**. The periodontal membrane has a uniform width around the root and apex.

Table 2.4 Descriptions of Tooth Development Stages (Demirjian 1973).

Figure 2.3 Schematic drawing of Demirjian 8 stage system used to identify Tooth Development Stages (A to H).

Each stage is allocated a score, with the combined scores for all the teeth giving the overall dental maturity score, ranging from 0 to 100 (using a system devised by Tanner for skeletal maturity (Tanner et al. 1983). This score is then converted directly into a dental age, by comparing the median value using tables and graphs, with a maximum age of 16.0 years for both genders (Demirjian et al. 1973). No measure of the variability of the dental maturity score was possible as the 95% CI was not given.

For this method, all 7 permanent mandibular teeth were required (the contra lateral tooth could be substituted, if a lower left tooth was absent), but a score could only be allocated if all 7 teeth were assessed. This meant the method could not be used for subjects with hypodontia, a limitation of the method for general application. If all 7 mandibular teeth assessed were at stage H (apex complete) the total score was 100, for which no dental age was available for boys (The maximum score for boys was 98.4, which corresponded to 16.0 years, but for girls a score of 100 equalled 16.0 years).

In addition, third molars were excluded as they were considered to show great variation, thus again limiting the value of this technique for DAA of young adults, as this system was applicable from ages 3 to 17 years (Demirjian et al. 1973). The sample consisted of 1446 boys and 1482 girls, giving a total of 2928 children, aged from 2 – 20 years and all of French-Canadian origin.

Although this method has been widely used, some investigators have encountered difficulties when applying the technique to their own populations. One of the problems may be due to the lack of clarity in the methodology published by Demirjian (Demirjian et al. 1973; Demirjian & Goldstein 1976), resulting in tables being derived from regression lines “smoothed manually to provide best fit lines” (Teivens & Mörnstad 2001).

2.3.3 Mörnstad et al

This measurement method (Mörnstad et al. 1994) used linear parameters taken from DPT’s mounted on a digitizing table, in order to construct multiple regression models. The cross-sectional sample consisted of 541 DPT’s of Swedish children, with the majority of children aged between 8 – 9 years. Seven measurements of molar teeth and three of premolar and single-rooted teeth were performed on all 16 permanent mandibular teeth (Figure 3.2), although the teeth on one side only were used for the calculations as comparisons showed that there were no differences. The age of the child at the time of radiographic examination was calculated in days, allowing for leap years, to avoid rounding errors. Correlation coefficients for the apparent linear relationships were calculated, and variables were introduced into the multiple regression model.

The authors claimed that the mean difference between Dental Age (DA) and Chronological Age (CA) could be estimated to within 0.12 days (SD=326 days) for girls, and 0.44 days (SD=290 days). This resulted in a mean difference between DA and CA of several hours, although the SD of the mean difference was approximately one year. This was a startling level of claimed accuracy, with predicted age being within several hours of actual age, which seemed improbable. However, the authors concluded that due to individual variation of tooth development in children, the mean difference between DA and CA was about ± 1.5 – 2.0 years at the 95% level. In addition, these models were designed to be used for children up to the age of 14 years, thus limiting the value of this technique to children.

None of the above mentioned methods were tested on a study sample separate from the Reference Data Set and compared to CA, in order to assess the accuracy of their methods. This is a general inadequacy of the research into dental age estimation.

2.4 Dental Age Assessment (DAA) database

To address the above concerns, a new approach to Dental Age Assessment (DAA) was developed (Roberts et al 2008). This was based on a Microsoft Access™ database (DAA database) derived from the DPT's of a large sample population of children and young adults from the London area, for whom the age of attainment for each TDS score was recorded. The database was used to produce a Reference Data Set (RDS) of the ages of attainment of individual Tooth Development Stages (TDS).

All the upper and lower permanent teeth in the left side were assessed using the 8 stages as described by Demirjian (1973). It is important to be aware that only the first part of Demirjian's technique, i.e. the description of the TDSs were used, not the dental maturity scores. The four third permanent molars were also included, if present, as variation between jaws and left-right symmetry for third permanent molars has been described (Mincer et al. 1993). This resulted in a total of 18 teeth available for assessment.

The ages of attainment were obtained using queries written in Access, and then exported into Microsoft Excel™ to calculate the summary data including mean and SE for each TDS. (Stage H was excluded from analysis, as it was impossible to say when this stage had been reached). The weighted average of the available TDSs was used to produce an estimated DA. Although the meta-analysis command was used in STATA to determine the weighted averages, this was not a comparison of different studies. Therefore, the term 'weighted average' was a more appropriate description of the mathematical procedure. The estimated DA was compared to CA in a separate sample of 50 DPT's, independent from the RDS. The mean difference between CA and DA was -0.29 years, with DA overestimating age. The SD was 0.84 years, indicating the maximum likely difference between estimated DA and CA was 1.65 years (Roberts et al. 2008). The results were comparable to other DAA methods and justified further investigation.

Using the 8 stages described by Demirjian and the weighted averages method showed promise, but it was considered that using more stages would improve the accuracy of DA estimation. To investigate this, DPT's of individual patients were assessed using the 12 stages described by Haavikko (1970), and the 8 staging system of Demirjian (1973). It was thought that the 12 stage system may be more accurate, as the time interval between stages would be smaller. However, it is known that as the number of stages increases, the repeatability (or agreement) between measurements and examiners decreases (Thorson & Hagg 1991). Therefore it was important to compare DA using both the 12 and 8 stage systems.

It can be seen that several methods of DAA are available, but why is this important? The significance of age estimation, and the need to find accurate, reliable methods, has been highlighted by the increasing number of UASC arriving in the UK. This has been the subject of a judicial review and has been placed before the UK Supreme Court (www.supremecourt.gov.uk).

2.5 Age identification of living individuals

In 2007, a total of 3,525 UASC aged 17 or under applied for asylum in the United Kingdom, 2 per cent more than in 2006 (3,450). The majority were from Afghanistan (32%), followed by Iran (10%), China (9%), Iraq (9%), Eritrea (8%), Somalia (6%), Bangladesh (4%), Pakistan (2%), Nigeria (2%) and Sri Lanka (2%) (www.homeoffice.gov.uk 2008).

The distributions of ages of UASC 17 years and younger, in the UK in 2007 is shown in Figure 2.4 below. It can be seen that 51% of cases involve subjects claiming to be 16 -17 years of age.

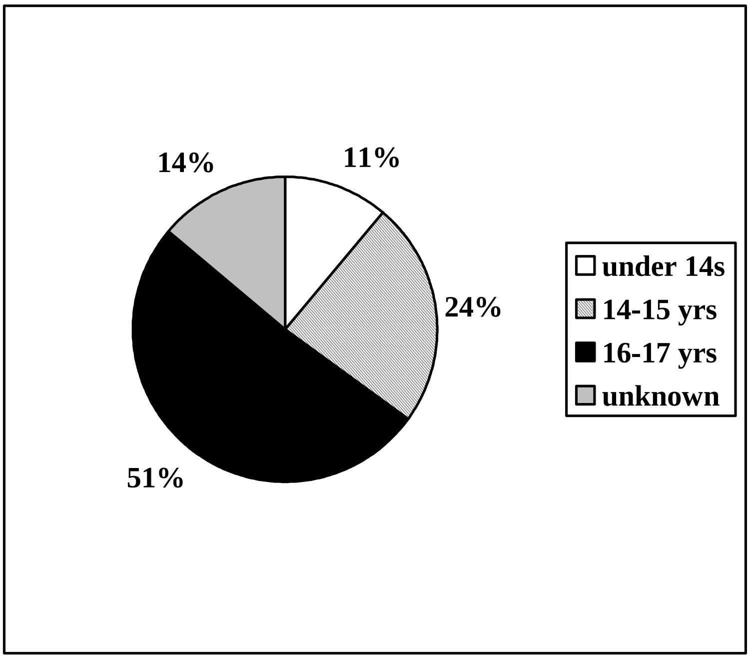


Figure 2.4 Applications for asylum in the UK from unaccompanied asylum seeking Children by age, 2007

The issue of child protection is of particular relevance in age disputed applications, as there are concerns relating to inappropriate accommodation and lack of access to existing child protection mechanisms for this vulnerable group. Likewise, there are concerns at mistaking adults as children, and placing them with other children, when this is clearly inappropriate (Crawley 2007). There are substantial differences in the judicial systems, state benefits, education and rights for individuals aged under or over 18 in the UK, therefore a reliable assessment of chronological age is important. There is no statutory guidance on the process of age assessment.

Dental age estimation is one of the methods currently used for Age Assessments in the UK, along with physical appearance, social history, interactions and demeanour, and development. This is a controversial area, with the Royal College of Paediatrics and Child Health stating the following: "*We accept the need for some form of age assessment in some circumstances, but there is no single reliable method for making precise estimates. The most appropriate approach is to use a holistic evaluation, incorporating narrative accounts, physical assessment of puberty and growth, and cognitive, behavioural and emotional assessments. Such assessments will provide the most useful information on which to plan appropriate management. The proposal to use X-rays is flawed on two counts. Firstly, there are clinical and ethical issues associated with the use of ionising radiation for this purpose, particularly in the absence of informed consent, and a clinical benefit from the procedure. Secondly, radiological assessment is extremely imprecise and can only give an estimate within two years in either direction. The information obtained would not contribute any greater accuracy to the assessment than the methods outlined above - and indeed would be less clinically useful"* (www.rcpch.ac.uk 2007).

Whilst a holistic approach to age assessment is to be encouraged, physical assessments of puberty and growth are flawed, as are cognitive and emotional assessments, due to the experiences UASC may have had to endure before arriving in the UK. A study of 166 UASC in Belgium showed that the prevalence of anxiety, depression, emotional problems and post-traumatic stress symptoms were high, with 10-25% exhibiting severe symptoms and 20-33% having very severe symptoms. These numbers were much higher than those found for accompanied refugee children and young adults (Derluyn & Broekaert 2007). Furthermore, the holistic approach has not been subjected to a separate sample, to test the accuracy. The use of ionising radiation without informed consent and explanation of the risks vs. benefits would not be advocated by any medical or dental practitioner, and the use of radiographs for age assessment is only allowable at the request of the individual to support his/her age disputed claim.

The imprecision of current age assessment methods highlights the need for further research in this area. The main flaws associated with dental age estimation are:

1) Inadequacy of current DAA methods.
2) Problems associated with ethnicity.
3) Assessing the dental age of older children and the use of third permanent molars.
4) Assessing the age of young adults and the 18 year-old threshold.

2.6 Problems with current DAA methods

There have been several studies comparing the validity of the different methods available for estimating dental age. Hägg & Matsson compared methods, and found a high rate of agreement between dental age (DA) and chronological age (CA) using the Demirjian method for children aged between 3.5 – 6.5 years of age, but less accuracy for older children. The Liliequist and Lundberg method showed low accuracy across all age groups, and the method described by Gustafson and Koch only demonstrated high accuracy for males, and displayed the poorest intra and inter-examiner agreement (Hägg & Matsson 1985).

Another study found that the Demirjian method over-estimated DA for both boys and girls by 6-10 months, whereas the methods of Haavikko and Gustafson and Koch underestimated DA by approximately 7 months. The authors proposed possible ethnic differences between the test and Demirjian samples as a possible cause of the over-estimation, although without any evidence to support this claim (Staaf et al. 1991).

Because of the possible influence of ethnicity, Mörnstad et al compared the methods of Demirjian (and the Scandinavian reference tables produced by Kataja et al. 1989), as well as Gustafson and Koch, Liliequist and Lundberg and Haavikko. They found the highest accuracy of DA vs. CA was using the Demirjian method with the Scandinavian reference data (Kataja et al 1989) with an over-estimation of 0.1 – 0.8 years (Mörnstad et al. 1995). They also found that the Haavikko method showed good validity, but under-estimated age for children aged 9 to 12 years old.

Kullman compared the accuracy of two of his methods; the subjective 7 stage method (Kullman et al. 1992) and the metric measurement technique (Kullman 1995). It was found that the measurement error and standard deviation for the measurement method was high (up to 2.3 years) as compared to the subjective method (up to 1.8 years).

Olze et al used the mandibular left third permanent molar to compare five methods, with the highest correlation found between DA and CA for Demirjian's method, although the Gleiser & Hunt and Kullman methods scored equally highly for intra and inter-examiner assessments. This study used eta coefficients of categorical-by-interval association; therefore it was not possible to calculate the actual mean difference between DA and CA (Olze et al. 2005).

The methods of Haavikko, Demirjian, Nolla and Willems were compared, and found that Willems was the most accurate, followed by Demirjian, Haavikko and Nolla. Demirjian tended to overestimate age, whereas the other methods underestimated dental age, and that the accuracy of all methods decreased for 16-year-olds (Maber et al. 2006).

Cameriere compared their own method of measuring root apex widths with Demirjian's stages and Willems method. They found that the accuracy of the Cameriere method was better than Willems, which in turn was better than Demirjian's method. The accuracy of all three methods decreased with increasing CA (Cameriere et al. 2008).

Current methods of DAA are all less accurate when applied to populations of different ethnicity from the reference population, and also when applied to older children. The issue of differences due to ethnicity is an under explored area.

2.7 Ethnicity

Ethnicity is derived from a Greek word meaning a people or tribe. Definitions of what constitutes an 'ethnic group' or 'ethnic minority' are subject to much debate. There is no consensus on what constitutes an ethnic group and this is because membership of any ethnic group is subjectively meaningful to the person concerned, and can be based on a combination of categories such as: country of birth, nationality, language spoken at home, parent's country of birth and skin colour and religion. Ethnic boundaries are imprecise and fluid (Senior & Bhopal 1994).

The widely used method of Dental Age Assessment (DAA) developed by Demirjian et al (1973) is relatively easy to use, but investigators have found differences when trying to employ the method for their own populations. The original tables were derived from tooth formation data from children of French – Canadian origin. There are many questions regarding the applicability of Demirjian's standards for children and adolescents of different ethnic and racial backgrounds, with both 'under' and 'over' estimation of dental age being a common problem (Loevy & Goldberg 1999; Eid et al. 2002).

Several recent publications show differences obtained when using Demirjian's method when applied to different populations (Koshy & Tandon 1998; Nykanen et al. 1998; Liversidge et al. 1999; Eid et al. 2002). One study investigated the possible effect of ethnicity in tooth development, but did not find a significant difference between groups (Liversidge et al. 2006). However, closer examination of this study reveals that the majority of subjects were of European origin (93%), therefore sample sizes for ethnic groups for individual TDS were small. In addition, heterogeneity of the overall sample and lack of calibration of all the observers, mean the results must be treated with a degree of caution, and further investigation of the ethnicity in tooth development is indicated.

In fact, most of the studies researching age estimation by dental development have been based on children of European descent. Growth of children from other ethnic or racial groups may not be appropriately represented. This applies to somatic growth (Chinn et al. 1996; Sun et al. 2002; Saxena et al. 2004) and also for tooth growth (Schmeling et al. 2001). Studies investigating skeletal age and sexual maturation have found differences amongst the various racial groups, with children of African descent being on average more advanced than their European counterparts (Mora et al. 2001; Sun et al. 2002).

The influence of racial differences in tooth eruption is well documented (Garn et al. 1972; Oteyumi et al. 1997; Mugonzibwa et al. 2002; Psoter et al. 2003). The role of ethnicity and race in tooth formation is less well reported, but differences between varying populations have been observed for third permanent molars (Olze et al. 2003; Olze et al 2004; Blankenship et al. 2007; Liversidge 2008b). Olze et al (2004) compared the lower right third permanent molar in German, Japanese and black South African populations. It was found that Japanese males and females were approximately 1-2 years older than their German counterparts when they reached Demirjian stages D-F. Significant age differences between the South African and Japanese samples were found for stages D-G, with South Africans approximately 1-4 years younger than Japanese subjects on reaching these stages (Olze et al. 2004). These results appear to support the effect of ethnicity in third permanent molar development, a view supported by Liversidge who found that Black South Africans were significantly more advanced than White, Bangladeshi and Cape Coloured children for almost all stages of third permanent mineralization (Liversidge 2008b).

Interestingly stage H was not significantly different between the German, Japanese and South African subjects (Olze et al. 2004). This highlights the need for caution when presenting reference data for stage H as the mean value is dependent on the upper age limit of the sample. The need for censoring data for stage H is discussed in detail in section 4.1.6.

Estimating age for individuals of different ethnic origin against standards derived from European populations is of limited value, as it may disadvantage the applicant.

If a particular ethnic group is shown to mature faster, then comparing them with other ethnic groups may suggest that they are older than their chronological age. New reference standards are required that are representative of the ethnic groups of unaccompanied children seeking asylum. Ideally these reference standards should be produced in the country of origin of the individual. This is not generally feasible, due to problems such as security, economics, available equipment and personnel, and limited levels of birth registration.

An alternative is to use a sample population consisting of a variety of ethnic groups, to examine the possible effects of ethnicity on dental development. London is suitable for this purpose, as it has the highest proportion (45%), of ethnic minorities in the UK with 78% of all Black Africans, 61% of Black Caribbean's and approximately 50% of all Asians resident in the UK. Minority ethnic groups also have a younger age structure than the white population, reflecting recent immigration and fertility patterns (www.statistics.gov.uk 2004). This provides a sample of children and young adults from which to derive reference standards for dental development for the main ethnic groups, for both genders.

To date, only differences between Caucasian and Bangladeshi British children have been compared using Demirjian's standards (Liversidge et al. 1999; Liversidge 2008b). The earlier study used a small sample of 521 Caucasian and Bangladeshi children, but did not indicate how ethnicity was verified. The authors questioned the suitability of Demirjian's standards for British children and supported the need for population specific standards (Liversidge et al.1999), a sentiment expressed by Demirjian himself (Demirjian et al. 1973). Standards should also be revised from time to time, to reflect current populations, in the same way that standards for height and weight are updated. For such data to be representative of all UK subjects, the role of ethnicity in tooth formation needs to be investigated, as there is little evidence available on different ethnic groups. For this reason, the data should be collected prospectively, with ethnicity recorded at the time of assessment.

There is a need to produce a system of age assessment using the dentition of living subjects so that reference ranges can be produced for each Tooth Developmental

Stage (TDS) discernible in each of the 16 morphologically distinct tooth types. (The maxillary and mandibular teeth on one side are required as differences between jaws have been recorded). The individual variation in tooth formation must always be considered, and whilst no one system can claim to be 100% accurate, the use of carefully planned and robust statistical analysis should enable reliable reference data for UK subjects.

In addition to the issues regarding ethnicity for dental age assessment, another problem is the reduced number of developing teeth available as children get older.

2.8 Third permanent molars

Dental age assessment is a particular problem when trying to determine whether a young person is less or more than 18 years of age. It is claimed that by 15 years of age, the apices of the majority of the permanent teeth have closed, with only third permanent molars remaining as immature teeth, and only until approximately 22 years of age (Olze et al 2004). This tooth shows considerable variation in its development and is the tooth most commonly developmentally absent. Prevalence data for absence of the third permanent molar varies from 7-32% in the population (Bolaños et al. 2003). The third permanent molar has been shown to be more variable than the other permanent teeth, and is not included in the Demirjian method. Whilst variability in formation stages of the third permanent molar has been demonstrated, correction must be made for the fact that variability of all developmental phenomena increases almost linearly with age. The age-corrected variability of the third permanent molar was not markedly greater than for the other posterior teeth (Garn et al 1962).

This raises the question, as to whether it is appropriate to regard an individual as 100% mature if the third permanent molar is present, still developing and excluded from methods of DAA. By ignoring the third permanent molar, one of the few remaining maturity markers still developing in this age group, valuable information about an individual of unknown age is excluded.

There are significant differences between the maxillary and mandibular third molars, with the recommendation that all available third permanent molars should be used in age determination (Mincer et al. 1993; Willerhausen et al. 2001; Solari & Abramovitch 2002; Bolaños et al. 2003).

Studies investigating the reliability of the third molar for age estimation have produced varied results (Thorson & Hagg 1991; Kullman et al. 1992; Willerhausen et al. 2001; Solari & Abramovitch 2002; Gunst et al. 2003; Olze et al. 2003; Olze et al 2006; Orhan et al. 2006), as shown in Table 2.5. Willershausen et al studied 1202 DPT's and found the difference between DA and CA to be not more than 1.1 years apart after applying the 95% confidence interval, although they do not explain how they came to this value in their methodology (Willerhausen et al. 2001). Mesotten et al (2003) looked at third permanent molars by assessing 1175 DPT's and found the SD for males and females ranged from 1.01 to 1.52 and from 1.41 to 1.73 years respectively (Mesotten et al. 2003). Whereas Arany et al (2004) assessed 1282 DPT's and found a mean difference between DA and CA of 1.6 years, with an SD of 1.2 years, giving a 95% confidence interval of 2.3 years (Arany et al. 2004). These are seemingly too wide to be of practical use for DAA.

From Table 2.5 it can be seen that the mean difference between DA and CA ranged from 0.5 – 3.5 years, with SD from 1.1 – 3.9 years, therefore the use of third permanent molars needs to be used with caution (Blankenship et al. 2007). However the inclusion of the third permanent molar, if available, allows for a measurement in an age group with a reduced number of maturity markers.

Authors	Year	Method used	Sample size	Age range (years)	Males vs. females?	Ethnic origin of subjects	Teeth assessed	mean CA – DA	SD (years)
Thorson & Hagg	1991	Demirjian	372	14.5-24.5	Yes	Unknown	38	0.5-3.5	1.4 M, 2F
Kullman et al	1992	Kullman	677	unclear	Yes	Surnames	38,48	Not stated	1M, 2F
Mincer	1993	Demirjian	823	14-24	Yes	White and Black	18,28,38,48	1.6	1.2
Willerhausen et al	2001	Kullman	1202	15-24	Yes	Surnames	18,28,38,48	Not stated	1.1
Solari & Abramovitch	2002	Demirjian	679	14-25	Yes	Hispanic	18,28,38,48	1.03-1.5	1.2
Mesotten et al	2002	Kohler et al	1175	16-22	Yes	Caucasian	18,28,38,48	Not stated	1.5
Olze et al	2003	Demirjian	3031	12 - 26	Yes	German & Japanese	18,28,38,48	Not stated	Not stated
Bolanos et al	2003	Nolla	786	4-20	Yes	Unknown	18,28,38,48	Not stated	3.4M, 3.9F
Gunst et al	2003	Köhler	2513	15.7-23.3	Yes	Caucasian	18,28,38,48	Not stated	1.5
Aranay et al	2004	Demirjian	1282	14 – 24	Yes	Japanese	18,28,38,48	1.6	1.2
Da Salvia et al	2004	Demirjian	400	14.4-25	Yes	Spaniards	48	Not stated	2.5
Prieto et al	2005	Demirjian	1306	14 – 21	Yes	Spaniards	38, 48	Not stated	Not stated
Orhan et al	2006	Demirjian	1134	4 -20	Yes	Turkish Caucasian	18,28,38,48	Not stated	Not stated
Blankenship et al	2007	Demirjian	1200	14-24.9	Yes	White and Black	18,28,38,48	Not stated	Not stated
Meinl et al	2007	Demirjian	610	12-24	Yes	Surnames	38,48	Not stated	Not stated
Martin-de las Heras et al	2008	Demirjian	572	14-22	Yes	Surnames	38	Not stated	Not stated
Sisman et al	2008	Demirjian	900	8-25	Yes	Turkish white	38	Not stated	Not stated
Liversidge	2008	Moorrrees	3224	5 – 23+	Yes	White, Asian & Black	38	Not stated	Not stated
Lee et al	2009	Demirjian	3301	4 – 26	Yes	Korean	18,28,38,48	Not stated	Not stated

Table 2.5 Comparison of different studies using third permanent molars for age assessment

The difficulty arises when assessment is required for individuals with fully developed permanent dentitions, i.e. those whose teeth have all attained stage Ac (Haavikko1970) or stage H (Demirjian 1973). Once a tooth has completed development, it provides limited information, as it only means a person has attained a certain age, but not how far they have progressed beyond it (Maber et al. 2006). For this reason, other markers need to be considered for young adults requiring age assessment. Other features such as DMFT index, eruption of third molars and periodontal recession of second molars have been shown to be insufficient for age estimation (Olze et al. 2005). The use of hand/wrist ossification for age estimation after 14 years of age is more difficult, as changes in the carpal bones are not clear (Cameriere et al. 2006). Other markers which appear to offer greater reliability include root canal measurements (Kvaal et al. 1995) and maturation of the sternoclavicular joint (Kreitner et al. 1998; Schmeling et al. 2004).

2.9 Other methods to estimate age

2.9.1 Root canal measurements

Studies have shown that with aging, the dental pulp cavity gradually becomes smaller because of continuous secondary dentine deposition (Kvaal et al. 1995). This physiological phenomenon is discernible in both erupted functioning and unerupted teeth, although the initial region of deposition varies, with deposition beginning in the pulp chamber of functioning teeth and apically in unerupted teeth (Morse 1991). Pathological changes in the pulp can occur as a result of trauma, caries, and tooth surface loss, and differentiating between physiological and pathological changes can be difficult. Radiographs help in the differential diagnosis of age-related pulp changes, as trauma, caries and tooth surface loss can usually be accounted for. Studies have investigated age estimation from dental radiographs and concluded that regression analyses of various pulp measurement ratios showed significant correlation with age (Kvaal et al. 1995; Cameriere et al. 2004; Bosmans et al. 2005).

The main criticisms of the above studies are that the effects of magnification and distortion of radiographs on measurements are difficult to accommodate in the assessment process. Formerly x-ray films and callipers have been used to measure the dimensions of the pulp (Kvaal et al. 1995). This has been superseded, as most centres now employ digital radiographs; therefore a technique that can be used for digital images is desirable. However, using digital images requires the use of specialised computer software, limiting the applicability for general use in DAA.

Another approach is the use of a subjective assessment of root canal width, using categorical grading (in a similar manner to staging of the developing tooth as described previously). The width of the distal root canal of the 3 permanent mandibular molar teeth on the left side (LL6, LL7 and LL8) if present were assessed and graded from 1 to 5 (Figure 5.1). A detailed description of the method is described in section 5.1.2.1.

2.9.2 Ossification of the Sternoclavicular Joint

Whilst most bones have completed ossification in young adults, a secondary epiphyseal ossification center appears at the end of the medial end of the clavicle, the Sternoclavicular Joint (SCJ) during adolescence, and completes fusion with the clavicular shaft during the third decade of life (Kreitner et al 1998). The ossification of the SCJ could be used to establish if a person is under or over 18 years of age, particularly for subjects whose teeth have fully developed, i.e. stage Ac/H. In these instances, dental age estimation methods are not applicable, and therefore other methods are required to estimate the age of the individual. For this reason, x-rays of the SCJ are recommended by the Study Group on Forensic Age Diagnostics for age estimation of living individuals, as well as DPT's and x-rays of the left hand (Schmeling et al 2006).

The ossification of the SCJ has usually been divided into either 4 stages (Schulze et al 2006) or 5 stages (Schmeling et al. 2004; Schulz et al 2008a). For conventional x-rays the 5 stages as classified by Schmeling et al (2004) are commonly used (Figure 2.5). Several studies have produced reference ranges for their local populations, using conventional radiography, CT scans and ultrasound scans of the SCJ (Kreitner et al. 1998; Schmeling et al. 2004; Schulz et al. 2005; Schulze et al. 2006; Schulz et al. 2008b; Quirmbach et al. 2009). Differences between males and females have been noted, with females reaching stage 3 (Figure 2.5) one year earlier than their male counterparts. Gender differences were not noted for other stages (Schmeling et al. 2004).

Figure 2.5 Classification of SCJ stages (Schmeling et al 2004).

The usefulness of stage 5 is limited for age estimation, as there is no way to assessing how much an individual has matured beyond this stage (there is no upper limit once maturation has been completed, as is also found with stages Ac/H for tooth development). This issue has not been addressed by previous studies.

The combination of DAA, hand x-ray and assessment of the SCJ has been advocated by the international and interdisciplinary Study Group on Forensic Age Diagnostics (AGFAD) in Germany for age assessment of individuals of unknown age (Schmeling et al. 2006). However the reproducibility of the SCJ method (inter-examiner agreement only) has only been assessed in one study (Schulze et al. 2006) and concerns have been raised about skeletal maturation and ethnicity (Clarot et al. 2004). Therefore the validity of the ossification of the SCJ for age estimation remains questionable and further work is needed.

The combination of root canal measurements, ossification of the SCJ and the methods of DAA has not been attempted. It is hypothesised that by pooling the results of the different techniques, the degree of variation and uncertainty in age estimation can be improved. By combining the above techniques, the maximum amount of information about the remaining developing structures in an individual can be obtained.

2.10 Aims of the Study

1. To compare four methods of Dental Age Assessment (DAA) against chronological age:
    - Haavikko (1970)
    - Demirjian et al (1973)
    - Mörnstad (1994)
    - Weighted average (Roberts et al 2008)

2. To compare the difference between using 12 and 8 stages in the weighted averages method, and assess the effect of:
    - Gender
    - Ethnicity
    - Third permanent molars

3. To assess the combination of DAA, Root Canal Width (RCW) and Sternoclavicular Joint (SCJ) for age estimation in young adults

2.11 Objectives

1. To further develop the DAA database using a multi-ethnic sample of children and young adults from the UK population.

2. To compare commonly used methods of dental age assessment, against known chronological age, to determine accuracy and reproducibility of the assessment methods.

3. To compile a reference data set for the developmental stages of permanent teeth on dental radiographs. (This will be derived from the technique which most accurately estimates age using tooth development).

4. To identify differences in reference data for ethnicity and gender.

5. To determine the relationship between root canal measurements and chronological age.

6. To assess the relationship between ossification of the Sternoclavicular Joint, and chronological age.

7. To investigate the effect of combining data from 3, 5 or 6 above and determining whether there is an improvement in the accuracy of age estimation compared with the techniques used individually.

3. Comparison of the four DAA methods

The aim of this chapter was to compare four methods of estimating age from the developing permanent dentition.

3.1 Methods

3.1.1 Study Design

This was a cross-sectional study based on patients of known age, attending the Eastman Dental Hospital (EDH) and Kings College Hospital (KCH), both in London, for dental or medical assessment. Data regarding ethnicity and any medical and/or dental anomalies were collected.

3.1.2 Data Protection and Ethical Approval

Ethical approval was received from the University College London Hospital (UCLH) Joint Research and Ethics Committee (project number: 03 / E023). The study was registered under University College London (UCL) Data Protection (Ref: Z6364106/2004/3/33, Section 19), and data protection regulations were followed.

3.1.3 Sample selection

The sample was derived from a convenience sample of children and young adults attending the Departments of Paediatric Dentistry and Orthodontics, and requiring dental radiographs for treatment planning. Radiographs were obtained both retrospectively and prospectively from EDH and KCH medical records. Prospective subjects were identified by the completed consent forms, and retrospective records identified from a list of all patients within the age range specified.

3.1.3.1 Inclusion criteria for dental radiographs

Subjects eligible for the dental study were as follows:

- Children and young adults aged from 4-24 years requiring dental radiographs for treatment planning.
- Dated radiographs of diagnostic quality.

3.1.4 Material used for assessments

3.1.4.1 Consent forms

Initially, ethical approval at EDH required consent from patients to re-use radiographs (although this was later expanded to include archived radiographs for which consent was not required). This was also an opportunity to obtain ethnicity information, as this was not always recorded in the clinical notes. Eligible patients were invited to participate (Appendix 6), and informed written consent/assent was obtained from the young adult or person with parental responsibility (Appendix 7) where appropriate.

A copy of the consent form was filed in the patient's notes, and another copy collected by the clinician and placed in a designated box in the clinic, to be collected by the primary investigator at the end of the clinical session. The notes for the relevant patients were then requested by the primary investigator (PI) from medical records on a monthly basis.

3.1.4.2 Dental radiographs

The dental radiographs used were DPT's. The machine used for taking DPT's at EDH was a Plan Meca™ (PM 2002 CC Proline), with a variable anode voltage of 64 – 66kV, and an anodic current between 0.4 – 0.8 mA. The exposure time was between 15 – 18 seconds with a magnification factor of 1.45. The film used was Agfa, size 15cm x 30cm, with a Kodak Regular™ intensifying screen, and films were developed in an AFGA Curix 260™ developing machine. All radiographs were converted to a digital image for analysis and storage using a Canon EOS 3000D™ digital camera, on an x-ray viewing light box. Each DPT was coded with a patient ID number only.

At KCH, a Plan Meca™ (PM ProOne) digital machine was used, with 2 – 7 mA anodic current and variable anode voltage of 60 - 70 kV. Various exposure times were available, depending on the program selected, and the magnification factor ranged from 1.45 – 1.98. As the image was digital, the DPT could be assessed directly via the PAX software, on a PC monitor 19’’ flat screen (Dell OptiPlex 746 DT™).

3.1.5 Assessment of Radiographic images

3.1.5.1 Assessment of the dental radiographs

At EDH, the images were captured and stored as jpeg files of 2.5MB each, with no compression. Assessments were performed using PaintShopPro™ (Corel®, Ottawa, Canada) software. This enabled enlargement of the image for assessments. At KCH, digital images were viewed using the PAX software, which allowed enlargement of the image if necessary.

3.1.5.2 Nomenclature for teeth

The British Dental Journal (BDJ) system (Table 3.1) was used for assessment of teeth using the 8 stage Demirjian system. The International Dental Federation (FDI) system (Table 3.1) was applied for assessment of the teeth using the 12 stage Haavikko system.

Tooth Nomenclature (BDJ Notation)	Tooth Nomenclature [FDI Notation]	Anatomical Description of Teeth
UL1	21	Upper Left Permanent Central Incisor
UL2	22	Upper Left Permanent Lateral Incisor
UL3	23	Upper Left Permanent Canine
UL4	24	Upper Left First Premolar
UL5	25	Upper Left Second Premolar
UL6	26	Upper Left Permanent First Molar
UL7	27	Upper Left Permanent Second Molar
LL1	31	Lower Left Permanent Central Incisor
LL2	32	Lower Left Permanent Lateral Incisor
LL3	33	Lower Left Permanent Canine
LL4	34	Lower Left First Premolar
LL5	35	Lower Left Second Premolar
LL6	36	Lower Left Permanent First Molar
LL7	37	Lower Left Permanent Second Molar
UR8	18	Upper Right Third Permanent Molar
UL8	28	Upper Left Third Permanent Molar
LL8	38	Lower Left Permanent Third Molar
LR8	48	Lower Right Permanent Third Molar

Table 3.1 BDJ and FDI nomenclature for teeth.

3.1.6 The four DAA methods

The gold standard of Chronological Age (CA) was calculated in days, by subtracting date of birth from the date the radiograph was taken, and dividing by 362.25 to convert to decimal years.

The methods of assessing dental age to be compared were:

- Haavikko (1970)
- Demirjian (1973)
- Mörnstad (1994)
- Weighted averages method (Roberts et al 2008)

The above methods were compared against known CA on a convenience sample of 50 consecutively selected DPT's. These were not included in the DAA database. It was decided to use 50 DPT's, as this was a feasible and practical sample size to collect, assess and analyse in order to compare the four methods for ease of use and time involved in carrying out the assessments. The time consuming methods could be later dropped.

The procedure to obtain Dental Age (DA) is illustrated with an example. The DPT in Figure 3.1 was taken of a male (subject Y) of 7.9 years of age.

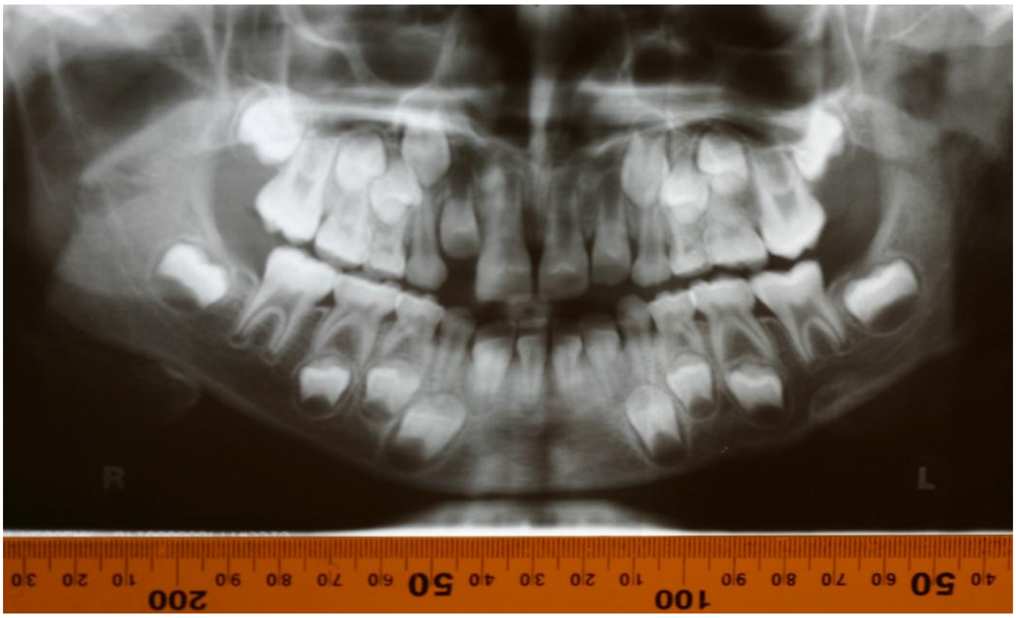


Figure 3.1 DPT of subject Y, male aged 7.9 years

3.1.6.1 The Haavikko method

All upper and lower teeth, including third permanent molars if present, on the left side of the DPT were assessed and each Tooth Development Stage (TDS) graded according to the 12 stages defined (Haavikko 1970), (Figure 2.1). Each tooth was assessed according to the criteria and the appropriate stage assigned. When a tooth was between stages, the stage already attained was recorded. Teeth that were missing or not visible were recorded as such, although if the corresponding tooth was available on the right side, this was substituted. This resulted in a maximum of 16 teeth being available for assessment.

Therefore for subject Y, the following scoring was obtained:

UPPER								
Tooth	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**
Stage	$R_{3/4}$	$R_{1/2}$	$R_{1/4}$	Ri	Crc	Rc	$Cr_{3/4}$	-
Median age	7.3	8	7.3	-	8.1	7	6.9	-
LOWER								
Tooth	**31**	**32**	**33**	**34**	**35**	**36**	**37**	**38**
Stage	Ac	Rc	$R_{1/4}$	Ri	Crc	Rc	$Cr_{3/4}$	-
Median age	7.1	7	8.1	-	7.3	6.4	6.7	-

Table 3.2 Assessment of DPT using Haavikko method.

The median ages of attainment for each stage, which were sex specific, were obtained from the original paper (Haavikko 1970) (NB: median ages for stage Ri were not given in the original paper. Also no third permanent molars were present in subject Y; therefore only 12 teeth out of a possible 16 were available for assessment).

The Dental Age was calculated as follows: = (sum of median ages) / (number of teeth assessed) = **7.3** years.

3.1.6.2 The Demirjian method

The lower permanent teeth (excluding the third permanent molar) on the left side of the DPT were assessed and graded according to the 8 stages previously defined (Demirjian & Goldstein 1976), Figure 2.2. For subject Y the following stages were given:

Tooth	**LL1**	**LL2**	**LL3**	**LL4**	**LL5**	**LL6**	**LL7**
Stage	H	G	E	D	D	G	D

Table 3.3 Assessment of DPT using Demirjian method.

The sum of the stages was converted into a maturity score using the tables and graphs provided in the original paper (Demirjian et al. 1973). The dental maturity score for subject Y was 733, which corresponded to an age = **8.1** years.

3.1.6.3 The Mörnstad method

The lower permanent teeth on the left side of the DPT were assessed. The image was converted from a jpeg to a tiff file in order to use the ShapeFind 2D™ software designed at the Eastman Dental Institute (ShapeFind 2D™)[b]. This meant that it was possible to locate the reference points of individual teeth directly from the computer screen (Figure 3.2).

For single rooted teeth, 5 individual points of reference were required

1. cusp tip (tip)
2. cemento-enamel junction mesial (cm)
3. cemento-enamel junction distal (cd)
4. root apex mesial (rm)
5. root apex distal (rd)

(Points 1–3: } to measure crown height (CH); points 4–5: } to measure apical width (AW))

Root length (RL) was defined as the average of the distance from cm to rm, and cd to rd (i.e. the average of the mesial and distal root length).

[b] This software is copyrighted to Professor Peter Hammond, UCL Institute of Child Health

For multi-rooted teeth, 7 points were required as shown in Figure 3.2.

1. cusp tip (tip)
2. cemento-enamel junction mesial (cm) — to measure crown height (CH)
3. cemento-enamel junction distal (cd)
4. root apex mesial 1 (rm1) — to measure apical width of mesial root (MAW)
5. root apex mesial 2 (rm2)
6. root apex distal 1 (rd1) — to measure apical width of distal root (DAW)
7. root apex distal 2 (rd2)

AAW was defined as the average of MAW and DAW. MRL was the distance from cm to rm1, and DRL the distance from cd to rd1, and the average of these was ARL.

A 10cm ruler was also incorporated on the photograph, to allow distances and ratios to be obtained.

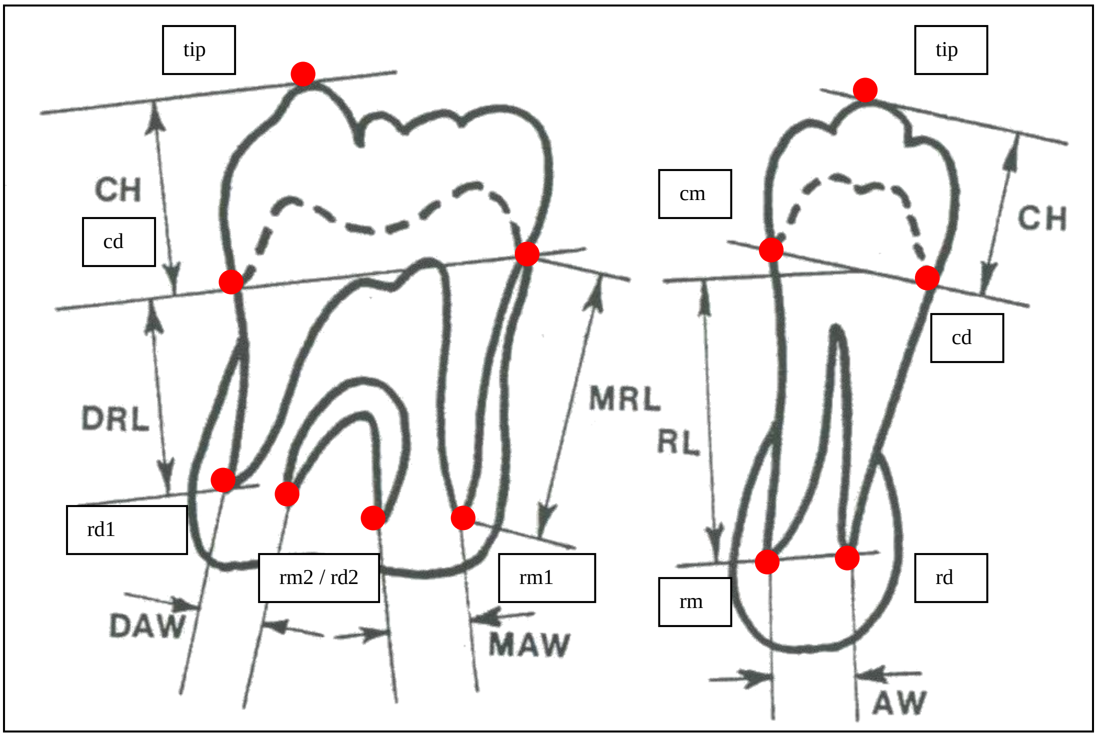


Figure 3.2 Reference points and measurements required for ShapeFind2D software.

Not all teeth contributed points to the final analysis, for example a tooth with no root contributed crown height (CH) but not root length (RL) or apical width (AW). Likewise a fully developed tooth with a closed apex provided CH and RL but not AW. Once the reference points had been plotted, the software calculated the distances (via ratios) between the required points and the results were imported into Excel (Microsoft Excel XP 2000 ™). An example of the measurements for subject Y is shown in Appendix 5.

In the original paper (Mörnstad 1994), the relationships between age, CH, RL/ARL and AW/AAW were "graphically displayed to find intervals in which the development of the structures in question were linearly correlated to age in a sensible manner. At this screening for usable correlations, both sexes were tested together". The correlation coefficients (Pearson product-moment correlation) were calculated for the whole age range (6-14 years) as well as the following intervals: 6-10, 8-12 and 10-14 years with the two sexes studied separately. Lastly, variables were introduced into a regression model using a stepwise procedure. The variables with the highest individual correlation coefficients between age and distance were entered first, and then the next highest variable remaining after adjustment for the independent variable already entered into the equation. The process was repeated until all inclusion ($p<0.05$) had been met, resulting in the following regression equations for both genders:

BOYS:

6-14 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of RL for LL4) + *d* (distance of AAW for LL6) – *e* (distance AW for LL5).

6-10 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of RL for LL3) + *d* (distance of AAW for LL6).

8-12 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of DAW for LL6) + *d* (distance of AW for LL3) – *e* (distance RL for LL3).

10-14 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of AW for LL3)

GIRLS:

6-14 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of RL for LL4) + *d* (distance of AAW for LL6) – *e* (distance AW for LL3).

6-10 years: Age = *a* + *b* (distance of RL for LL4) + *c* (distance of AW for LL1) + *d* (distance of ARL for LL7) – *e* (distance AAW for LL6).

8-12 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of RL for LL4) + *d* (distance of AW for LL3) – *e* (distance DAW for LL6) + *f* (distance of AW for LL4).

10-14 years: Age = *a* + *b* (distance of ARL for LL7) + *c* (distance of AAW for LL7) + *d* (distance of ARL for LL8).

To calculate the age of a subject, the measurements for the required teeth were substituted into the above equations and dental age derived. Clearly if the tooth had completed development (i.e. the equivalent of stage H/Ac), the apical width would be zero, and AW or AAW could not be calculated. Therefore the method could not be used for individuals with fully developed teeth. The values for the variables *a* to *f* were dependent on gender and age band, as demonstrated in Table 3.4.

Gender	**Age**	**Variable**					
		a	b	c	d	e	f
Boys	6-14	3068	79.8	29.6	182.3	24.7	
	6-10	2893	41.8	18.6	104.5		
	8-12	3186	53.8	108.6	44.6	20.0	
	10-14	3835	62.5	91.5			
Girls	6-14	2902	67.1	37.3	115.1	24.0	
	6-10	2817	42.0	126.2	33.4	69.0	
	8-12	3358	37.7	22.6	36.7	110.6	36.7
	10-14	3867	47.5	105.9	72.4		

Table 3.4 Variables for the regression equations in the Mörnstad method.

The r^2 value for boys in the 6-14 years equation was 0.78; therefore 78% of the total variation was explained by the regression model, with an SD of 622 days, or 1.7 years. For girls, the r^2 value was 0.77, indicating that 77% of the total variation was explained by the model and the SD was 543 days (1.5 years).

The age (but not the gender) of the 50 subjects was not known at the time of the assessment so the regression equations for 6-14 years by gender were used.

Therefore for subject Y, the regression formula was:

DA = 3068 + (79.8 x 1.7) + (29.6 x 2.2) - (182.3 x 2.6) - (24.7 x 6.2)

= 2641.7 days

= **7.2** years

3.1.6.4 The Weighted average method

All the upper and lower teeth on the left side of the DPT were assessed, and all four third permanent molars if present, using the 8 stage system described by Demirjian (Figure 2.2). The scores derived were recorded onto a paper copy along with patient details of each subject; an example of the scoring for an assessment is demonstrated (in blue) in Figure 3.3. The record card also allowed assessment using the 12 stages as described by Haavikko, but this was not performed at this stage.

Filename: Subject Y											
Hospital No:							**Ethnicity:**				
Mother's origin:							**Father's origin:**				
Haavikko	**21**	**22**	**23**	**24**	**25**	**26**	**27**	**28**		**18**	**28**
	31	**32**	**33**	**34**	**35**	**36**	**37**	**38**		**48**	**38**
Dermirjian	**21**	**22**	**23**	**24**	**25**	**26**	**27**			**18**	**28**
	G	F	E	E	E	G	D			-	-
	31 H	**32** G	**33** E	**34** D	**35** D	**36** G	**37** D			**48** -	**38** -
Notes											

Figure 3.3 Record card for dental assessment.

Recording teeth

If a tooth was not assessed, the reason why was recorded. There were six possible categories:

1. Present
2. Missing (extraction)
3. Missing (hypodontia)
4. Missing (developmentally absent)
5. Missing (limited view on radiograph)
6. Missing (poor image)

A separate code was required for teeth missing due to hypodontia or developmentally absent. This was particularly important for the later developing teeth, such as third permanent molars, and if categorised incorrectly, could artificially inflate the hypodontia prevalence in the sample population.

The number of teeth in each of the categories was determined (using Microsoft Access™ queries), to investigate the prevalence of hypodontia in the sample population, and determine the latest age at which the third permanent molar developed.

Generating the Reference Data Set

The stages were recorded in the DAA database (Microsoft Access™) in a form, along with the personal details of the subject and the date the radiograph was taken. The mean ages of attainment for each stage of each tooth were acquired by writing Access queries for each TDS. An example of the Structured Query Language (SQL) required to determine the mean age of attainment for the UL1F is shown:

UL1F: IIf([UL1-F]=0,Null,([dor]-[dob])/365.25)

CA in years was calculated from date of birth (dob) and date of radiograph (dor) as described above. These queries were imported into Microsoft Excel™ and a spreadsheet was produced for each TDS (one per column) of all subjects in the DAA database. Summary statistics for each TDS were produced for the count (*n-tds*), mean, SD and SE, using Microsoft Excel™ StatPlus formulae. (Table 3.5).

Tooth	Stage	n-tds	Mean (years)	SD (years)	SE (years)
UL1	F	22	7.2	0.9	0.2
UL2	F	47	7.6	1.2	0.2
UL3	E	43	7.3	1.0	0.2
UL4	D	51	7.2	1.1	0.2
UL5	D	33	7.3	1.0	0.2
UL6	G	50	8.1	1.3	0.2
UL7	D	54	7.6	1.2	0.1
UL8	-				
LL1	H				
LL2	G	15	8.4	1.9	0.2
LL3	E	45	6.9	1.1	0.2
LL4	D	21	6.5	1.1	0.2
LL5	D	26	7.2	0.8	0.2
LL6	G	48	7.9	1.3	0.2
LL7	D	48	7.5	1.1	0.1
LL8	-				

Table 3.5 Assessment of DPT of subject Y using Weighted average method.

The mean and SE of the assessed teeth, excluding stage H, were copied into Stata, and the weighted average was calculated using the meta-analysis command.

Meta-analysis is normally used to pool the results of several studies, not only by combining the results, but also taking into account the size of each individual study, giving a weighted average result and a measure of the variation. The two methods of performing meta-analysis are the fixed effects and random effects methods. The fixed effects method is usually used if heterogeneity between the studies is low, whereas the random effects model is used when there is moderate to high heterogeneity between studies. The random effects model has a larger 95% CI to reflect the larger uncertainty (www.nottingham.ac.uk\rlos).

The decision whether to use a random effects or fixed effects model was not straightforward; on the one hand it seemed more appropriate to use the random effects model as the heterogeneity was high in some cases. This reflected the fact that the DAA database consisted of a sample of children and young adults contributing to the mean, SD and SE for each TDS. Whilst this was true, the teeth in an individual were obviously closely related, and therefore the fixed effects model was also appropriate. In practice the difference between the fixed and random models was not relevant, as the DA was the same.

To estimate DA for an individual, the teeth rather than the studies were pooled, therefore the term ‘weighted average’ was preferred to meta-analysis. The weighted average is similar to the normal average, but instead of all data points contributing equally to the final result, some data points are weighted more than others. The weight (w_i) can be determined from the formula:

$$w_i = n_i / s_i^2 = 1/se_i^2$$

where n = n-tds, s = SD, se = SE and i means from 1 to 18 teeth.

Therefore the larger the variance (s^2), the smaller the weight, and the less that tooth will contribute to the weighted average. To calculate the weighted average, the formula is:

$$\text{Weighted average} = \frac{\sum w_i m_i}{\sum w_i}$$

Where m is the mean age of attainment, and i means from 1 to 18 teeth.

(Taylor 1997).

The results of a meta-analysis are usually displayed as a forest plot (Figure 3.4), with each line and square signifying a single study and the length of the line representing the 95% CI for that study. The diamond at the bottom of the plot represents the pooled result. The forest plot in Figure 3.4 for subject Y shows the individual TDS as boxes, with the size of the box proportional to the weighting of the TDS. It can be seen that the boxes are not the same size, indicating that some TDS carry more weight in the meta-analysis than others, due to differences in SD, and *n*. The length of the horizontal line indicates the 95% CI. The width of the diamond at the bottom of the plot indicates the 95% CI for the pooled estimation of DA, which here is less than one year.

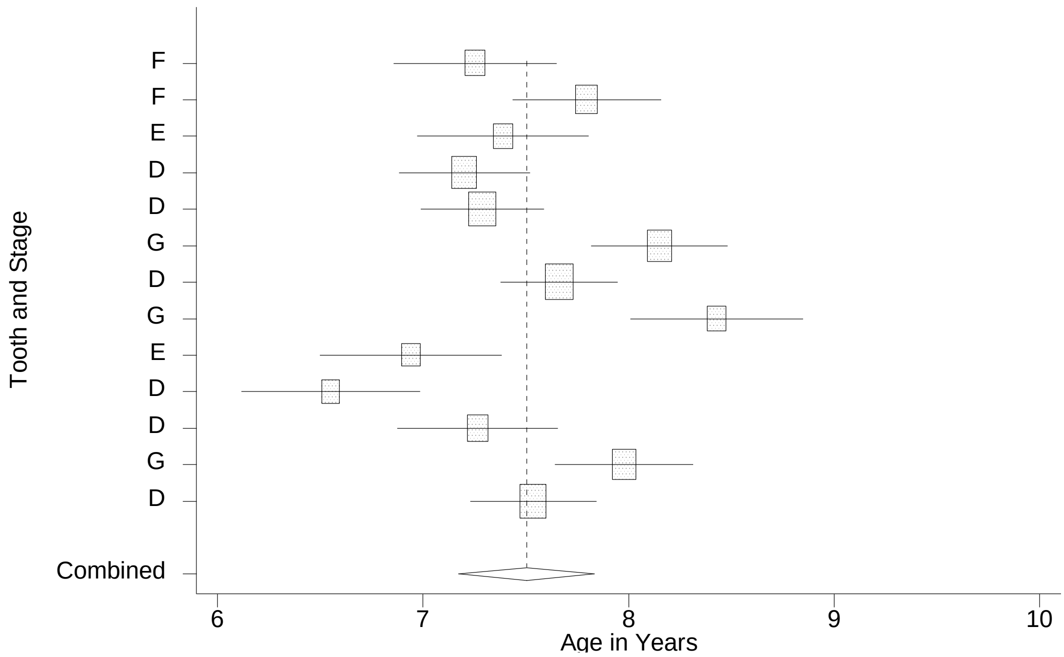


Figure 3.4 Forest plot of meta-analysis for subject Y

The advantage of using the weighted average method means that the 95% CI of the *pooled* mean can be calculated. It is important to note that this is not the same as the 95% CI for subject Y, as this is larger than the pooled mean and depends on the SD of each TDS. However some indication of the uncertainty of the estimated age is ascertained by looking at the 95% CI pooled mean, which indicates the range of years for 95% of the sample population with the same teeth.

Therefore for subject Y Dental Age = **7.6 years (95% CI 7.2 to 7.9 years)**.

3.1.6.5 Age estimation for subject Y

The results of the four methods for subject Y (CA = 7.9 years) are shown (Table 3.6):

Method	Age (years)	DA – CA (years)	95% CI (years)
Demirjian	8.1	0.2	
Haavikko	7.3	-0.4	
Mornstad	7.2	-0.7	
Weighted average	7.6	- 0.3	7.2 to 7.9

Table 3.6 Summary of age estimation for subject Y using the four methods

For subject Y, the Demirjian method slightly overestimated age, whereas the other methods underestimated age. The weighted average method gave a 95% CI range of 1.3 years, however it must be remembered that this was the 95% CI for the sample population and not for subject Y.

3.1.7 Training

Training of the PI was undertaken in the following:

- Assessment of DPT's using the methods of Demirjian (1973) and Haavikko (1970), weighted average (Roberts et al 2008) and Mörnstad (1994)
- Microsoft Access version 2003
- Microsoft Excel version 2003
- ShapeFind 2D software
- Stata statistical package (Statacorp, version 9 intercooled).

3.2 Statistical Considerations

3.2.1 Outcome measures

The primary outcome measure for this study was the difference between DA and CA for each of the four methods. The significance of the difference between DA and CA was tested using *t*-tests for each method. The 95% CI was used to determine the degree of uncertainty for each method.

3.2.2 Descriptive data

Summary statistics of the distribution of CA for each TDS: number of teeth (*n-tds*), mean age of attainment, standard deviation and standard error, were determined for the weighted average method.

3.2.3 Intra and inter-examiner agreement

To test for inter-examiner agreement 30 DPT's were examined twice by the PI after a two week interval. Inter-examiner agreement was assessed by two observers examining 10 DPT's twice. Cohen's Kappa *k* was used to measure the agreement between the two observations. This is considered more robust than simple percentage agreement, as kappa takes account of the agreement occurring by chance. Kappa has a maximum of 1.0 indicating perfect agreement, to zero indicating no better than chance. Landis and Koch (1977) produced guidelines to interpret kappa values (Table 3.7):

Value of kappa	Strength of agreement
<0.00	Poor
0.00 – 0.20	Slight
0.21 – 0.40	Fair
0.41 – 0.60	Moderate
0.61 – 0.8.	Substantial
0.81 – 1.00	Almost perfect

Table 3.7 Interpretation of Kappa values (Landis and Koch 1977).

DPT's were coded by ID number alone, and the two assessments were recorded on separate paper forms. They were subsequently transferred to an Excel spreadsheet and copied to Stata for the calculation of Cohen's Kappa.

3.3 Results

During the pilot phase of the study, the PI received feedback from participants, their parents, and clinicians regarding the clarity of the information sheets, ease of use of the consent form, and sensitivity of the ethnicity questions. The number of patients receiving DPT’s who chose not to participate, the number of individuals who needed to be contacted by post and also the return rate was investigated.

3.3.1 Recruitment for study

Initial recruitment of participants to the study was slow, and feedback suggested that completing three copies of the consent forms was too time consuming. In response to this, funding was awarded to purchase custom-made consent forms in pressure sensitive duplicating paper, so that signatures were only required once. Funding was provided by the Department of Paediatric Dentistry, Eastman Dental Institute (EDI) research fund and an Eastman Foundation for Oral Research and Training (EFFORT) grant. The foundation is a registered charity, which supports research carried out at EDI, by matching the funding provided by departments (£3262 in total). Ten individuals with eligible DPT's, but not consented, were identified in the first month of the study, and forms were sent with a letter of explanation and SAE. None of the consents were returned, despite a follow-up telephone call, therefore contacting patients by post was abandoned due to poor cost-effectiveness. Eight subjects out of 1522 (0.5%) declined participation in the study, five because they did not wish to participate and three because they did not want to record their ethnicity.

3.3.2 Intra-examiner agreement

Thirty DPT's were assessed twice for the Haavikko and Demirjian methods after one month. As the weighted average method used the Demirjian stages, both methods could be tested at the same time. The kappa values for the two assessments were 0.78 for Haavikko, indicating substantial agreement with a mean difference of 0.1 (SD 0.4) years. For Demirjian, the kappa value was 0.85 indicating almost perfect agreement and the mean difference between the two assessments was 0.1 (SD 0.3) years. The Mörnstad method was very time consuming, and reproducibility was only performed for 2 subjects, with a kappa value of 0.1 which was slight.

3.3.3 Inter-examiner agreement

Ten DPT's were assessed by two separate investigators (the PI and second supervisor) after a one-month period, and results gave kappa values of 0.60 for Haavikko, indicating moderate agreement, and 0.83 for Demirjian and weighted average methods, indicating almost perfect agreement.

3.3.4 Comparison of the methods

The 50 subjects chosen for the comparison of methods consisted of 19 males and 31 females, with an age range of 5 to 20 years. Of the 50 DPT's selected; 4 were excluded for the Demirjian method as assessment was incomplete (in two subjects, the 7 mandibular teeth had reached stage H, one subject had missing teeth and for one subject no score was available for the stage recorded). Six subjects were excluded from the Mörnstad (1994) method (as they were over 14 years). Two subjects were excluded from the Haavikko and weighted average method as all teeth had achieved apex complete / stage H. Therefore the remaining 43 DPT's were assessed according to the methodology previously described.

The database used for the weighted average method was based on an early version of the complete DAA database, with 1522 subjects contributing to the ages of attainment for the TDS.

The mean difference, SD, 95% CI and p value of the paired t test between DA and CA were calculated by the four methods for the 44 DPT's, as shown in Table 3.8. (The results for the 50 subjects are shown in Appendix 6).

Method	n	mean diff DA-CA	SD	95% CI	p value
Demirjian	43	0.7	1.1	0.3 to 1.0	0.002
Haavikko	43	-0.8	1.4	-1.2 to -0.4	0.002
Mörnstad	43	0.7	3.3	-0.4 to 1.7	0.2
Weighted average	43	0.2	1.1	-0.1 to 0.5	0.1

Table 3.8 Mean difference, SD, 95% CI (in years) and p value of paired t test, between DA and CA for the four methods.

The mean difference between DA and CA for the methods ranged from -0.8 years to 0.7 years, with Haavikko the largest (-0.8 years), and the weighted average method the smallest (0.2 years). The SD was smallest for the Demirjian and weighted average methods (1.1 years) and largest for the Mörnstad method (3.3 years). Haavikko underestimated age by -0.8 years. The other 3 methods all tended to overestimate age. Although the mean difference between DA and CA for all four methods was small, DA – CA for the 44 test subjects varied from 4.7 years (Demirjian) to 14.2 years (Mörnstad).

For the Demirjian and Haavikko methods, the differences between DA and CA were significantly different (p=0.002). With the Mörnstad and weighted average methods, the differences were not significant (p=0.2 and 0.1 respectively). The 95% CI of the difference was least for the weighted average method (0.6 years) and most for the Mörnstad method (2.1 years).

3.4 Discussion

The data discussed are the results from preliminary investigations into age estimation of children and young adults. The four methods differed in their ease of use, with the Mörnstad method taking considerably longer to perform compared to the other three methods. This may have affected the assessment and reproducibility, as it was sometimes difficult to visualise the points on the computer screen. Whilst better results might have been obtained using callipers and traditional radiographic films, the purpose of this study was to investigate DAA methods that could be utilised using digital images, as more clinicians are now using digital x-ray machines.

Of the staging methods, Haavikko with 12 stages was easier to remember and apply to images than Demirjian's 8 stages. This was because the Demirjian method had specific criteria for each stage, and careful scrutiny was required initially to allocate a stage. However, once the method had been performed several times, it became as easy to use as Haavikko.

The weighted average method used the same Demirjian stages, but some time was required to learn to use the DAA database and become familiar with the SQL required to write the relevant queries. In addition, to obtain the mean and SE for the 50 test subjects, the individual values for each TDS had to copied and pasted from Excel into STATA to determine the weighted average for each subject. Whilst this was not too time consuming for the small sample selected, it was not feasible to analyse all subjects in the DAA database by this method. This problem will be discussed further in chapter 4.

A problem highlighted soon after the start of the study was the difficulty in recruiting subjects for the DAA database, due to the need to obtain consent. The original consent forms required 3 separate signatures by the patient or parent, and added to the workload of clinicians and therefore uptake was poor. Once the consent forms had been changed to allow duplicate copies to be easily made, recruitment improved. In addition, the PI reminded all clinicians in the Department of Paediatric Dentistry at the monthly staff meetings about the study to increase numbers.

The sample size in this study was small, and this will have affected the precision of the difference between DA and CA obtained for the four methods. Fifty subjects were chosen as a reasonable number, as four methods were being tested, and considerable time was required for each method, particularly Mörnstad.

3.4.1 Limitations of the Haavikko, Demirjian and Mörnstad methods

The original Haavikko paper did not give data for stage Ri. This posed a difficulty in assessing subjects using the Haavikko method which had not been reported by other workers (when using this method for age estimation). It remains unclear how other studies have dealt with the absence of data for stage Ri, and there appears to be no logical reason for its omission in the methodology (Haavikko 1970). The author was contacted regarding this issue, but did not reply.

The Haavikko method resulted in an under-estimation of age, with DA being almost a year less than CA for the 50 test subjects. This is consistent with findings from other studies, several of them reporting under-estimation of age using the Haavikko method (Mörnstad et al. 1995; Maber et al. 2006).

The Demirjian method over-estimates age. This is a common finding when applying this technique to other populations (Hägg & Matsson 1985; Mörnstad et al. 1995; Maber et al. 2006). The inability of the Demirjian method to handle missing teeth, a fully formed apex (stage H) or third permanent molars, limits the use of this technique for dental age estimation.

The comparison of DA and CA yielded poor results with the Mörnstad method, with a mean difference of -0.7 years and SD of 3.3 years. This method also had the widest 95% CI for differences between DA and CA at 2.1 years and slight reproducibility (kappa – 0.1). It was decided not to investigate further the use of the upper teeth for this method. Even though DA and CA were not significantly different, the wide range of differences between DA and CA, and the limitation of age to 14 years meant this technique was not suitable for age estimation. For this reason, the

Mörnstad method was considered inappropriate for this study, and was not investigated further.

3.4.2 Limitations of the weighted average method

Gender was considered separately for the Haavikko, Demirjian and Mörnstad methods, as they provided separate tables or equations for boys and girls. The weighted average method did not separate subjects by gender, as the DAA database did not contain sufficient numbers by gender for each TDS at that time. Because of this, it was expected that the weighted average method would perform relatively poorly, in comparison to the other three methods, as gender has been shown to affect DA (Levesque et al. 1981). However, the weighted average method had the smallest mean difference between DA and CA, despite this shortcoming.

Ethnicity was also not considered separately for the 50 DPT's, due to the small sample size.

The weighted average method was the most accurate, with the smallest mean difference between DA and CA, an SD equal to Demirjian and the smallest 95% CI of the four methods. In addition, the difference between DA and CA was not significant (p= 0.1). However due to the small sample size, results need to be viewed with caution, and further work is needed to improve the sample size, analyse the data with respect to 12 or 8 stages, ethnicity and gender, before any definitive conclusions can be reached regarding the accuracy of the weighted average approach.

4.0 Further investigation of the weighted average method

The aim of this chapter was to determine the accuracy and precision of dental age estimation using the Demirjian and Haavikko staging systems with the weighted average method. In addition, the influence of gender, age and distribution of teeth was investigated. The effect of ethnicity on tooth development was also explored.

4.1 Methods

The same methodology as described in chapter 3 was used to obtain DPT's from Eastman Dental Hospital (EDH) and King's College Hospital (KCH).

4.1.1 Recording data

Each DPT was assessed according to the 12 stages as described by Haavikko (1970) and shown in Figure 2.1, and by the 8 stages described by Demirjian (1973) and shown in Figure 2.2. Using Excel functions, summary data for each TDS were calculated as follows; the number of individuals in that TDS (count, '*n-tds*'), mean age of attainment, median, standard deviation (SD), standard error (SE), minimum and maximum, range, centile values and upper and lower 95% confidence intervals. This data sheet was the Reference Data Set (RDS), and was produced separately for males and females (Appendices 8 & 9 for 12 stages, and 10 & 11 for 8 stages).

4.1.2 Recording ethnicity

For this study the National Statistics Census 2001 classification of ethnicity was used (www.statistics.gov.uk/census2001) (Appendix 1). This classification is the one used by the NHS, and is based on two levels of classification; with level 1 consisting of six different ethnic groups; White, Mixed, Asian or Asian British, Black or Black British, Chinese and Other ethnic group. Level 2 further subdivides into 17 subgroups to include the main ethnic groups in the UK. For the purpose of this study, classification was restricted to Level 1. The six main ethnic groups were allocated a code (Table 4.1):

Ethnic group	Code
White	1
Mixed	2
Asian	3
Black	4
Chinese	5
Other	6
Unknown	0

Table 4.1 Ethnicity codes

4.1.3 Estimating Dental Age

The DA of all subjects in the DAA database, with at least one permanent tooth still developing (not stage H / Ac) was calculated individually using the weighted average method described in chapter 3 (section 3.1.6.4). Previously, the mean and SE of each tooth had been copied into Stata, and the meta-analysis command used to obtain the DA for an individual subject. This was time consuming and not feasible for testing the whole DAA database. For this reason, the weighted average was calculated in Excel, using the indirect function and weighted average formula previously described (3.1.6.4). This required the stages for each subject assessed to be recorded by either the 8 or 12 stage methods, and therefore new queries had to be written in Access for this. An example of the SQL is shown in Appendix 7.

As differences between genders existed, males and females were analysed separately. This enabled rapid calculation of DA for all subjects in the DAA database and allowed further analysis by gender, age and ethnic group to be performed. Whilst it was possible to calculate the DA of the subjects in the DAA database and compare this to CA to determine the accuracy of the weighted averages method, it could be argued that using this self-referential sample introduced bias to the method. In reality, the bias would have been minimal as the influence of one individual in a database with a sample size of several thousand was negligible. However, this could have been considered a criticism of the method.

Therefore in addition to estimating the DA using subjects in the DAA database, an independent sample of 200 DPT's was randomly selected from patients attending KCH. A sample size of 200 was chosen as this number represents a reasonable, attainable size with the corresponding confidence interval smaller than the standard deviation of the observations (Altman 1991). This independent sample was not part of the DAA database and therefore the results would test if there was any effect on the accuracy of DA calculation between 12 and 8 stages. The 200 DPT's were assessed and recorded onto the DAA database with a separate code, so that they could be isolated from the main database. The estimated DA was derived in Excel, and compared to CA.

In addition to estimating DA, the subjects in the DAA database were used to investigate the possible effects of the following:

4.1.4 Comparison of the 12 and 8 stages

As all the subjects in the DAA database had been assessed using both the 12 and 8 stage systems, it was possible to determine the following:

4.1.4.1 The effect of the number of stages on the accuracy of DA estimation and repeatability.

By increasing the number of stages, the mean time interval between stages would be less, and therefore it was thought that the accuracy of DA estimation would improve. In contrast, increasing the number of stages resulted in poorer repeatability for both intra and inter-examiner agreement. By comparing the 12 and 8 staging systems, the balance between accuracy and precision could be explored.

4.1.4.2 Measure of agreement between DA and CA

Bland and Altman plots were produced to assess the agreement between DA and CA for the sample, by gender and age band. In addition, the plots were used to identify outliers in the database.

4.1.5 Differences by age band

It was thought that DA estimation was more accurate for children under 10 years of age, due to the increased number of permanent teeth still developing (section 2.1.5.2). To investigate this, the database was divided into groups of subjects greater and less than 10 years of age.

4.1.6 Stage H

Once the apex is fully closed, the tooth is of limited value for age estimation, as it is not possible to ascertain when the tooth matured, and for this reason stage H ages of attainment are not used in most DAA methods. This is illustrated by the cumulative frequency graph for the UL1H for females, with 1460 subjects (Figure 4.1) which shows the graph reaching a plateau at around the age of approximately 23 years, and a median age of attainment of around 16 years. This is clearly misleading as the apex of the UL1 normally closes at around 11-12 years. The pattern in Figure 4.1 arises from the large number of young adults in the database. Therefore appropriate censoring of stage H was required.

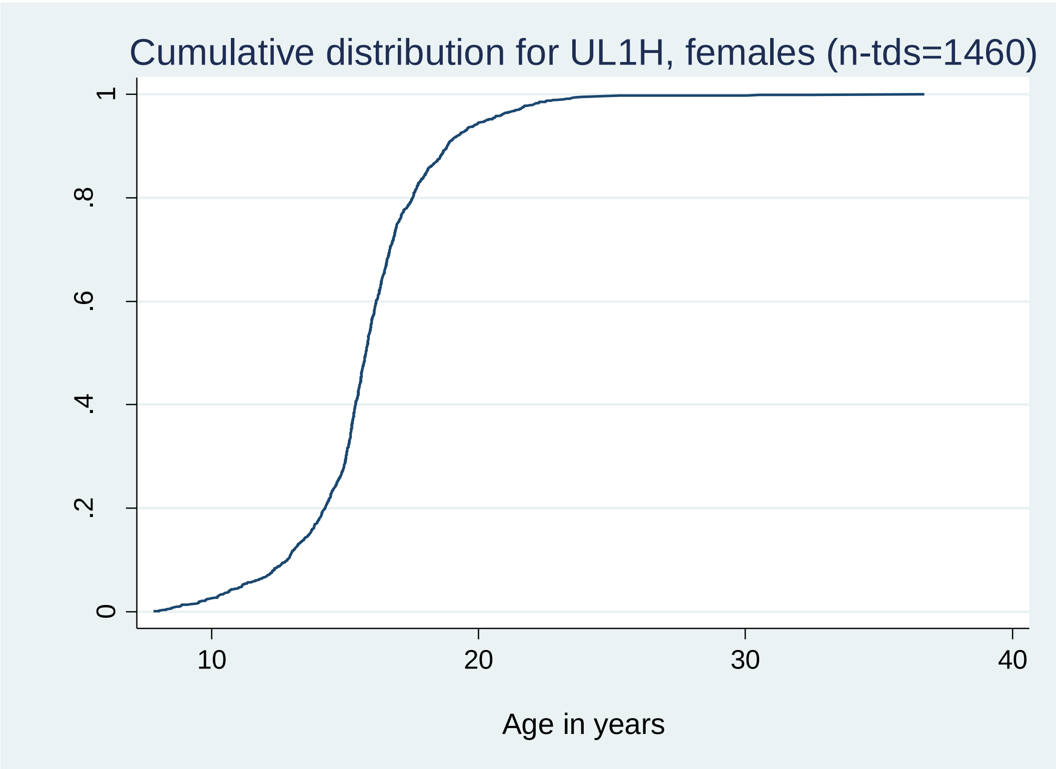


Figure 4.1 Cumulative distribution for UL1H for females.

Useful information could still be obtained from these stages however, by investigating the earliest age at which a tooth was no longer recorded as stage G and only stage H as illustrated in Table 4.2 for the UL1 (females). The oldest age at which G was attained is highlighted in bold, and this represented the upper age limit of stage G (11.3 years).

Age	**Stage**
10.9	G
11.0	H
11.1	G
11.2	G
11.3	**G**
11.4	H
11.7	H
11.8	H
11.9	H

Table 4.2 Upper limit of stage G for the UL1 (females).

Data above 11.3 years were censored, and the Access query for median ages of attainment repeated. This would indicate the age at which 50% of the sample population had reached stage H. The resulting cumulative frequency chart had fewer subjects (n-tds =198) compared to n-tds = 1460 before censoring, and the median age was around 10.5 years which is much closer to the age of apex closure of the UL1 seen clinically (Figure 4.2).

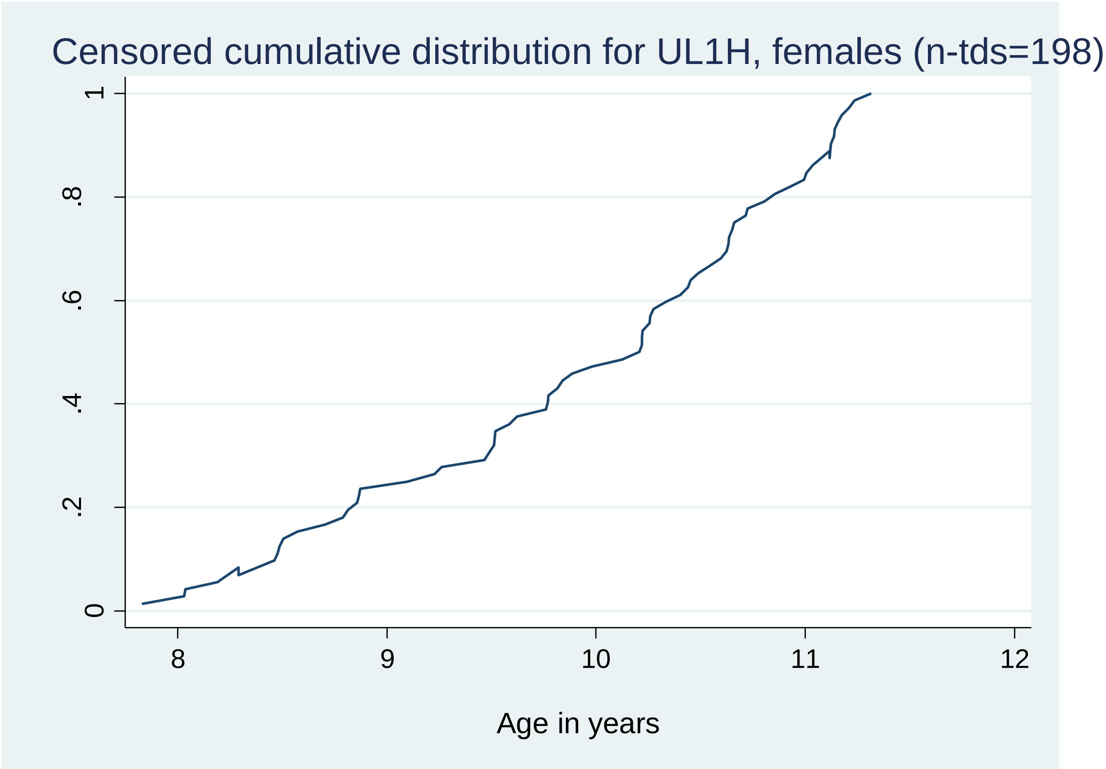


Figure 4.2 Censored cumulative distribution for UL1H for females.

4.1.7 Time interval between TDS.

Although tooth development had been divided into 8 stages, it was unlikely that the time interval between each stage was identical. The differences between mean ages of attainment for two stages were compared for each TDS and gender.

4.1.8 Differences by gender

The mean age of attainment between males and females for each TDS was analysed to compare with values quoted in the literature.

4.1.9 Third permanent molars

As stated in the literature review (section 2.9), the third permanent molars are the only permanent teeth still developing in young adults. The symmetry between right and left sides, and the mean age of attainment for these teeth was analysed, to see if it could be used to predict if a person was under or over 18 years of age. The 18 year-old threshold is particularly important for UASC to determine if a person is a child or adult, as discussed in section 2.6.

4.2 Differences between ethnic groups

To determine the effect of ethnicity on age of attainment of each TDS and estimated DA, the ethnic groups were compared using analysis of variance (ANOVA). If a statistically significant difference was observed, the different ethnic groups were compared pairwise. As there were 15 possible separate group pairings to compare, a modified p value of 0.003 (0.05/15) was considered statistically significant using the Bonferroni method (Altman 1991).

4.3 Statistical considerations

In addition to the statistical analysis described in chapter 3, the following were also analysed:

4.3.1 Sample size estimate

Statistical advice, from the main supervisor (Professor Tim Cole) had been sought from the outset to determine appropriate sample size. As this was not a hypothesis testing problem, it was not appropriate to attempt sample size calculations. The question in this explanatory research was “How precisely can the population size effect be determined from the sample data?” That is to say, does the sample allow for inferences to be drawn about the population? (Altman 1991). The WHO recommended at least 200 individuals in each age and sex group for reference standards (www.who.int). To extend this to each TDS of all the teeth and for each ethnic group under investigation was clearly not feasible within the resource and time constraints of this study. It was desirable to have as large a sample as reasonable, ideally with as many subjects (n=2928) as the Demirjian study (as this is one of the most commonly used methods).

4.3.2 Reproducibility

A further 10 DPT's were assessed twice by the PI and another investigator, after a two week period for both the 8 and 12 stages halfway through the study to check for intra and inter-examiner agreement.

4.3.3 Comparing CA vs. DA for 12 and 8 stages

As the CA and DA in an individual were related, to assess if the difference between CA and DA was statistically significant paired t tests were used.

4.3.4 Measure of agreement

Comparison of methods using correlation coefficients (r) was inappropriate, as r measures the strength of relation between two variables, not the agreement between them (Bland & Altman 1986). Therefore Bland and Altman plots were produced to compare the measurement of agreement between DA and CA. This was achieved by plotting the mean of DA and CA against the difference between DA and CA in Stata. In addition, the DA using either 8 or 12 stages were compared to see how closely they agreed with each other. Bland & Altman plots were also used to analyse the data initially for errors, as outliers could be identified and examined.

4.3.5 Testing for Normal distribution

It was desirable to determine if the data were normally distributed or not, in order to use the appropriate statistical tests. Distribution was assessed using histograms and bar charts, and data were tested for normality using the Shapiro Wilk Test for each TDS and by gender.

All data were analysed using Microsoft Access and Excel 2003™ and StatPlus 2003™ and Stata intercooled version. 9™ (Stata corporation 2003).

4.4 Results

4.4.1 Demographics of the sample

Of the 3051 subjects contributing to the DAA database, 2621 had ages of attainment for TDS. (The remainder consisted of subjects contributing to the RCW and SCJ study, as described in chapter 5). The characteristics of the DAA database are shown in Table 4.3.

Gender	Summary statistics	DAA database (n=3051)	TDS (n=2621)
Males	Number (%)	1371 (45%)	1178 (45%)
	Age range (years)	3.4 – 34.9	3.4 – 24.2
	Mean age (SD)	16.0 (6.0)	14.5 (3.8)
Females	Number (%)	1680 (55%)	1443 (55%)
	Age range (years)	1.8 – 32.7	1.8 – 24.6
	Mean age (SD)	16.5 (5.7)	15.1 (3.5)

Table 4.3 Characteristics of DAA database and TDS.

4.4.2 Status of teeth

The number and type of teeth present and missing are shown in Table 4.4. Data were only available for 2009 subjects regarding the status of the teeth (as it was not routinely recorded by all investigators) and is shown as bar charts for upper (Figure 4.3) and lower (Figure 4.4) teeth separately.

The tooth most commonly present in the sample population was the LL3 (98.3%) followed by the LL7 (98.2%) and the LL2 and UL3 (97.4%). The UL4 was most likely to be missing due to extraction (9.2%) followed by the LL4 (7.8%). The tooth most commonly excluded from the database due to poor image was the UL1 (2.0%) followed by the UL2 (1.8%). The low percentage of teeth excluded due to poor image indicated that it was possible to use DPT's for assessment of the upper and lower teeth for dental age estimation.

The tooth most commonly missing due to hypodontia was the LR8 (13.2%) followed by the LL8 (12.3%), UR8 (12.1%) and UL8 (10.5%). The LL5 (4.5%), the UL2 (3.2%) and the UL5 (3.0%) were the other teeth most likely to be affected by hypodontia. The different hypodontia prevalences between the four third permanent molars confirmed the lack of symmetry for this tooth, and the need to include all four teeth if present. The third permanent molars were also most likely to be missing developmentally (10-11%), as they develop at around 7-9 years, therefore radiographs taken before this age could not determine if the third permanent molar was missing due to hypodontia or yet to form.

In total, the prevalence of hypodontia in this sample was 3.8%, and less than 1% of the sample was excluded due to poor images.

Tooth	Present % (*n-tds)*	Missing (extracted) % (*n-tds)*	Missing (hypodontia) % (*n-tds)*	Missing (developmentally absent) % (*n-tds*)	Missing (limited view) % (*n-tds*)	Missing (poor image) % (*n-tds*)
UL1	96.5% (1938)	0.3% (7)	0.2% (4)	0	0.9% (19)	2.0% (41)
UL2	93.6% (1881)	0.5% (10)	3.2% (65)	0.1% (3)	0.6% (13)	1.8% (37)
UL3	97.4% (1957)	0.2% (4)	0.7% (15)	0	0.4% (8)	1.2% (25)
UL4	86.5% (1738)	9.2% (184)	1.5% (31)	0.1% (2)	0.6% (13)	1.3% (26)
UL5	92.6% (1860)	2.3% (47)	3.0% (61)	0.1% (3)	0.5% (10)	1.0% (20)
UL6	97.0% (1949)	2.3% (46)	0.2% (4)	0	0.1% (3)	0.3% (6)
UL7	97.8% (1964)	0.5% (11)	0.7% (15)	0.2% (4)	0.2% (4)	0.5% (10)
LL1	96.6% (1941)	0.1% (3)	1.3% (26)	0.05% (1)	0.7% (15)	1.1% (23)
LL2	97.4% (1957)	0.1% (2)	0.7% (14)	0	0.6% (13)	1.0% (21)
LL3	98.3% (1974)	0.05% (1)	0.3% (7)	0	0.2% (5)	1.1% (22)
LL4	89.5% (1799)	7.8% (157)	21.1% (3)	0.1% (2)	0.1% (3)	0.5% (11)
LL5	91.5% (1838)	2.9% (58)	4.5% (91)	0.3% (7)	0.1% (3)	0.3% (6)
LL6	96.0% (1928)	3.2% (64)	0.3% (6)	0.05% (1)	0.1% (2)	0.3% (6)
LL7	98.2% (1972)	0.4% (8)	0.9% (18)	0.1% (2)	0.1% (2)	0.3% (7)
UL8	76.9% (1544)	0.1% (2)	10.5% (211)	11.1% (224)	0.7% (14)	0.6% (13)
UR8	75.4% (1515)	0	12.1% (243)	11.2% (226)	0.8% (16)	0.4% (9)
LL8	74.9% (1505)	0.05% (1)	12.3% (248)	10.3% (206)	0.8% (17)	1.0% (20)
LR8	74.4% (1495)	0.1% (2)	13.2% (266)	10.2% (205)	1.2% (25)	0.8% (16)
Total	**90.6% (1820)**	**1.7% (4)**	**3.8% (75)**	**2.5% (49)**	**0.5% (10)**	**0.9% (17)**

Table 4.4 Status of teeth in RDS (n=2009).

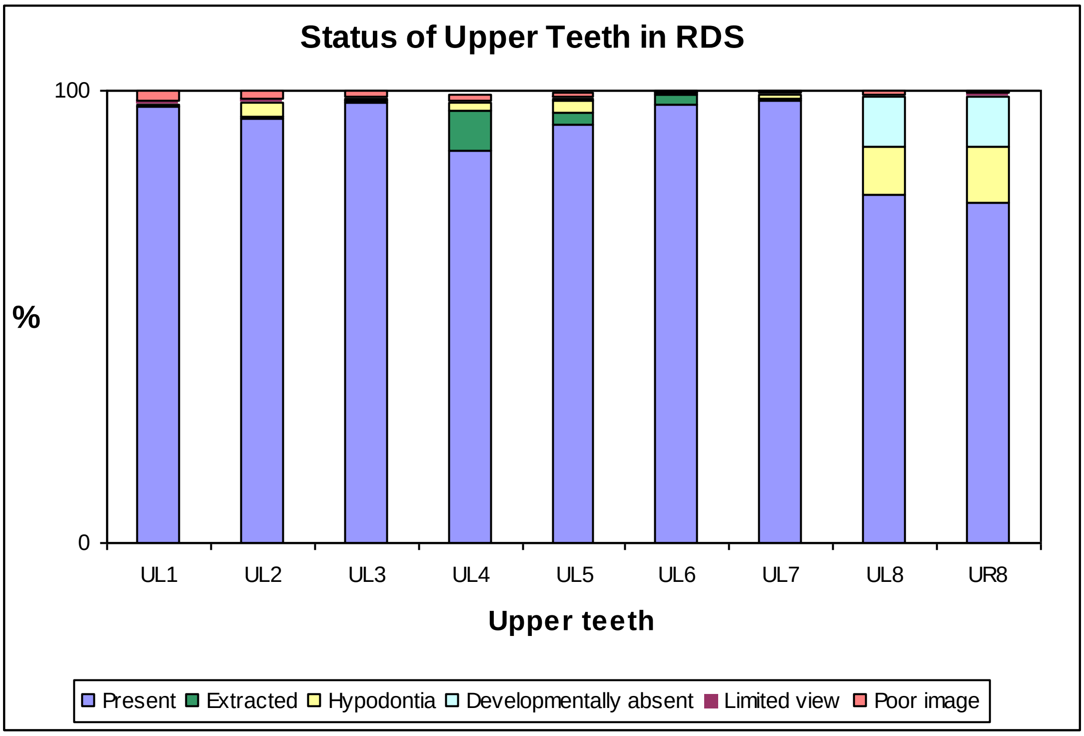


Figure 4.3 Stacked bar chart of the status of the upper teeth in the RDS.

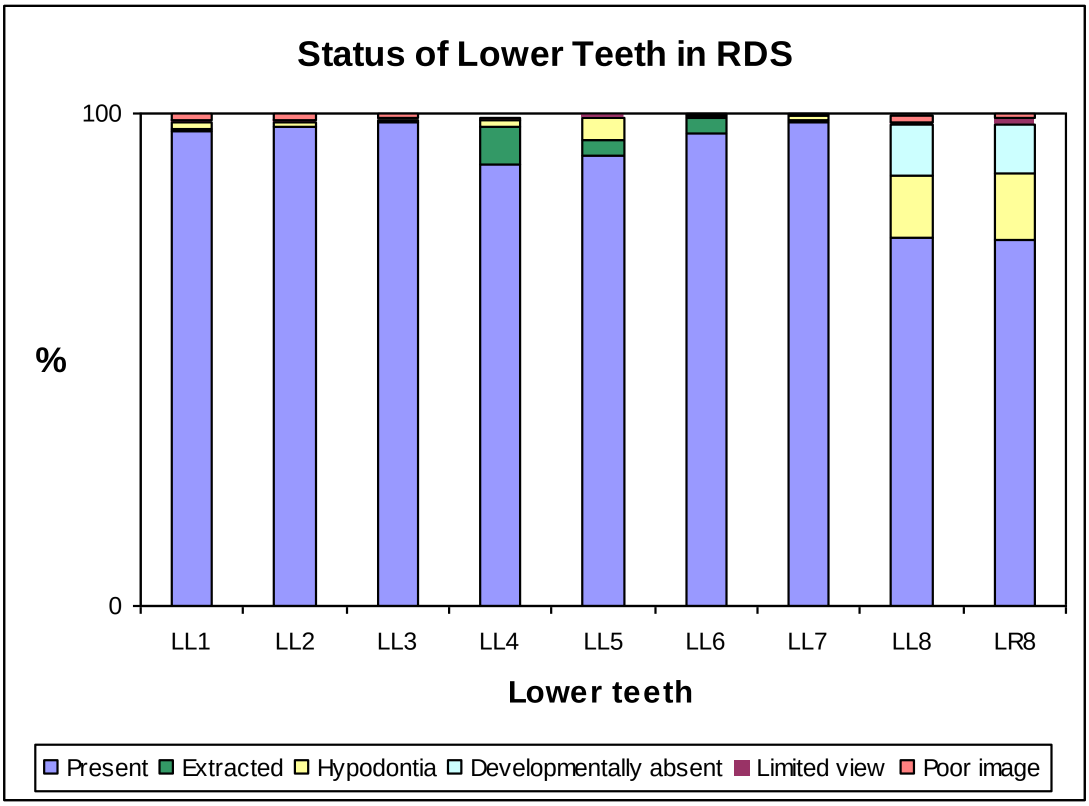


Figure 4.4 Stacked bar chart of the status of the lower teeth in the RDS.

4.4.3 Reproducibility of the methods

4.4.3.1 Intra-examiner reproducibility

The intra-examiner kappa value for the 12 stage method was 0.88 and for the 8 stage method was 0.92, indicating almost perfect agreement for both, but slightly better reproducibility for 8 stages.

4.4.3.2 Inter-examiner reproducibility

The inter-examiner kappa value was 0.79 for the 12 stages and 0.82 for the 8 stages system, indicating substantial and almost perfect agreement respectively. The intra-examiner agreement was better than the inter-examiner agreement for both stages.

4.4.4 Estimating DA using the DAA database

4.4.4.1 By gender

There were 2426 subjects who had been assessed using both 12 and 8 stages, for which the dental age could be calculated and compared (Table 4.5). The number of developing teeth per child was plotted against CA and it showed that the maximum of 18 teeth assessed was around 10-12 years, after which there was a decreasing number of teeth available for assessment (Figure 4.5). There were several subjects with 4-6 teeth still developing after the age of 20 years, which indicated the variation in dental development in individuals.

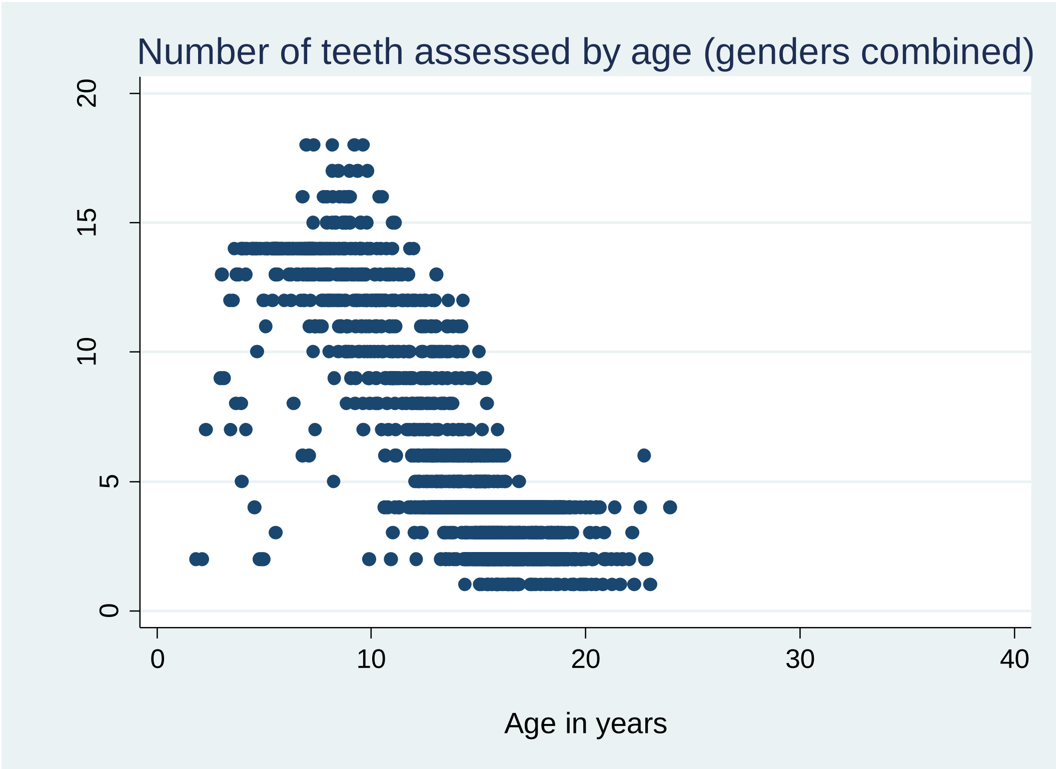


Figure 4.5 Scatter plot of number of teeth assessed by age for males and females.

Using 12 stages, the mean difference DA – CA was -0.15 years for males and -0.14 years for females (Table 4.5). The mean difference using 8 stages was the same for both males and females (-0.14 years). For both genders, the mean difference between DA and CA was negative, indicating that DA underestimated age.

Stage	Gender	N	Mean difference DA-CA (years)	SD of difference (years)	p value of DA-CA	95% CI of difference between DA-CA
12	Male	1086	-0.15	1.30	0.0001	-0.08 to -0.23
	Female	1340	-0.14	1.40	0.0002	-0.07 to -0.22
8	Male	1086	-0.14	1.29	0.0003	-0.06 to -0.22
	Female	1340	-0.14	1.43	0.0002	-0.07 to -0.22

Table 4.5 Mean difference, SD, p value using t test and 95% CI for both staging systems, by gender.

The SD of the difference ranged from 1.29 to 1.43 years, with smaller SD for males than females for both stages with the SD for 12 and 8 stages almost identical. The difference between DA and CA was statistically significant for both genders and both staging systems ($p<0.001$). The 95% CI of the difference between DA and CA was identical in females for both stages at 0.15 years and similar in males for the 12 and 8 stages at 0.15 and 0.16 years respectively. However it must be remembered that this was the 95% CI of the difference between DA and CA for the sample population, and not the 95% CI for an individual.

The results showed no difference in DA estimation using 12 or 8 stages, when comparing mean difference, SD, p value from the paired t test, or 95% CI between DA and CA, for either gender. The paired t test was used to test if DA = CA or DA – CA = 0.

4.4.4.2 By age group

To investigate if DA estimation was more accurate over or under 10 years of age, the DAA database was divided into two age bands and compared by gender and staging system (Table 4.6). For the <10 year age group DA was greater than CA whereas for >10 years, DA was less than CA for both genders and staging systems. The number of subjects under 10 years was clearly less than those over 10 years of age, representing a fifth of the males and an eighth of the females in the whole sample, and therefore there was less power to detect a difference between the groups. However, there is a clear trend for over-estimation of age for children less than 10 years.

The mean difference DA – CA was slightly larger for females under 10 years (0.3 years) as compared to females greater than 10 years of age (0.2 years) for both staging systems. The mean difference for females <10 years (0.4 years) was three times more than the mean difference for females in the whole sample (0.1 years) using 8 stages. The same trend was observed for females using 12 stages. The mean difference between DA and CA was similar for males both under and over 10 years of age using the 12 stages, but slightly larger for males under 10 years using 8 stages (0.3 years) compared to over 10 (-0.2 years).

The SD of the difference was much less for <10 years for both genders and staging systems, indicating the variability of the sample was less. The SD of the difference for >10 years was comparable to the SD of the difference for the whole sample for both genders, which was to be expected as it was most of the sample of the DAA database. The difference between DA and CA was highly significantly different for both age bands and genders. The range of values for the 95% CI for subjects >10 years of age were positive, with a range of approximately 0.17 years, indicating high precision. Whereas the range of 95% CI values for subjects less than 10 years were negative and the range was larger (0.3 years) indicating the uncertainty was larger for this age group, due to the smaller sample size.

Stage	Gender	Age (years)	n	Mean difference DA-CA (years)	SD of difference (years)	p value of DA-CA	95%CI difference DA-CA
12	Male	<10	174	0.2	0.7	0.0001	0.3 to 0.1
		>10	912	-0.2	1.4	<0.0001	-0.1 to -0.3
	Female	<10	147	0.3	0.9	<0.0001	0.5 to 0.2
		>10	1193	-0.2	1.4	<0.0001	-0.1 to -0.3
8	Male	<10	174	0.3	0.9	<0.0001	0.4 to 0.1
		>10	912	-0.2	1.3	<0.0001	-0.1 to -0.3
	Female	<10	147	0.4	1.0	<0.0001	0.5 to 0.2
		>10	1183	-0.2	1.5	<0.0001	-0.1 to -0.3

Table 4.6 Mean difference, SD, p value and 95% CI for <10 and >10 years, by gender and staging systems.

4.4.5 Measure of agreement for DA using 12 and 8 stages

To investigate how closely correlated the DA obtained using 8 and 12 stages, Bland - Altman plots were produced by gender.

Males:

The mean difference between DA using 8 stages (DA8) and 12 stages (DA12) was -0.002 years (SD 1.0 years), with the 95% limits of agreement from -1.9 to 1.9 years. Although the two DA were closely related (Pearson's r = 0.88) as expected, with the majority of points lying within the 95% limits of agreement, the discrepancy between DA8 and DA12 as age increased was clearly visible, demonstrated by the increasing scatter on the right hand side of the plot representing the older age group (Figure 4.6).

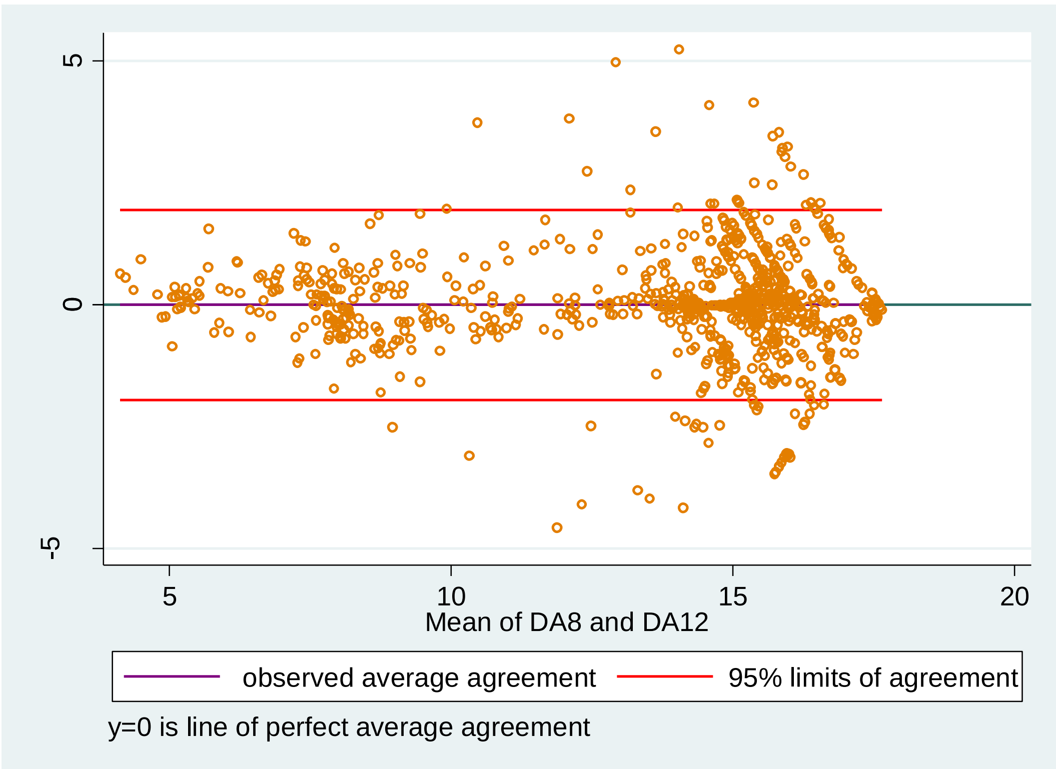


Figure 4.6 Bland - Altman plot of DA using 8 and 12 stages for males.

Females:

The agreement between DA8 and DA12 was better for females, with a mean difference of zero (SD 0.7 years), and 95% limits of agreement from -1.3 to 1.3 years. The increased dispersion with increasing age was again observed on the Bland – Altman plot (Figure 4.7).

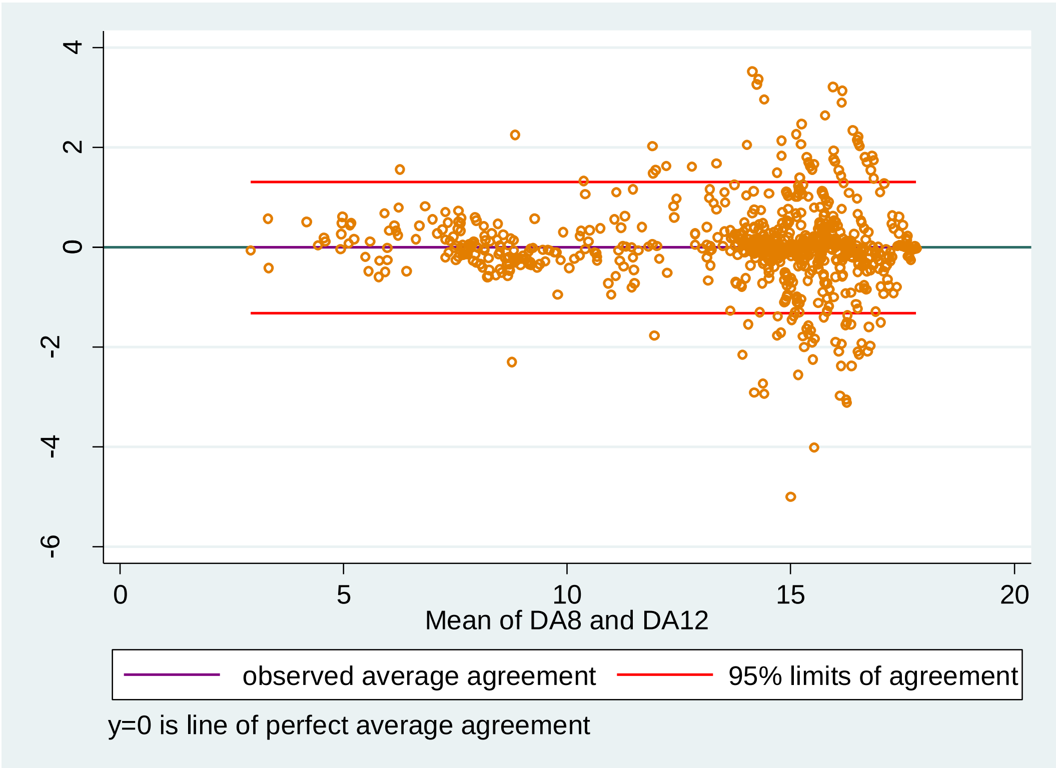


Figure 4.7 Bland - Altman plot of DA using 8 and 12 stages for females

The database was investigated to determine if either 8 or 12 stages consistently under or estimated age compared to CA. It was found that there was no pattern of estimation for either staging system for both genders.

4.4.6 Measure of agreement between DA and CA using DAA database

The accuracy of the DA estimation using either 8 or 12 stages was tested by comparing the DA estimated age for each child to her/his CA using the Bland - Altman method. This was tested for both genders by the two age bands (< 10 years and >10 years).

4.4.6.1 Males less than 10 years of age

The Bland - Altman plot (Figure 4.8) showed 95% limits of agreement (red lines) for the 174 males < 10 years from -1.4 to 2.0 years. (The 95% levels of agreement for males less than 10 years using 12 stages was slightly narrower, range = 2.9 years). The correlation between DA and CA was high (Pearson's r = 0.84), which was to be expected. The majority of subjects were above the zero line, indicating that DA was over-estimating age compared to CA. The scatter was slightly wider with increasing age, indicating that the DA was more variable with increasing age. Several outliers were clearly visible outside the red lines, but did not have any medical or dental conditions noted, and were of various ethnicities.

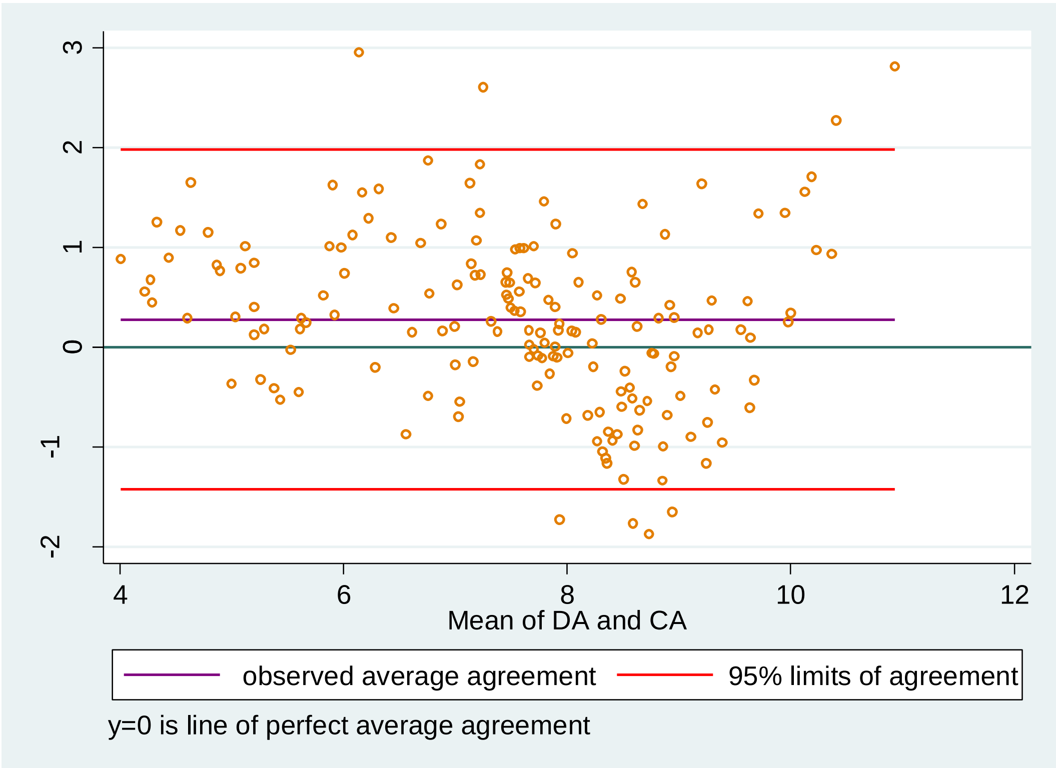


Figure 4.8 Bland - Altman plot showing measure of agreement between DA and CA for males < 10 years using 8 stages.

4.4.6.2 Males more than 10 years of age

Figure 4.9 shows the Bland - Altman plot, with the 95% limits of agreement from -2.9 to 2.4 years (range = 5.4 years). This range was much larger than for < 10 years and indicated the increased variation with increasing age in the sample. The majority of points were below the zero line, indicating a negative mean difference between DA and CA (0.2 years, SD 1.38). Greater scatter with increasing age was shown for the 912 males in this group. The outliers were investigated in the DAA database but no error, medical or dental condition or pattern of ethnicity was observed to explain them.

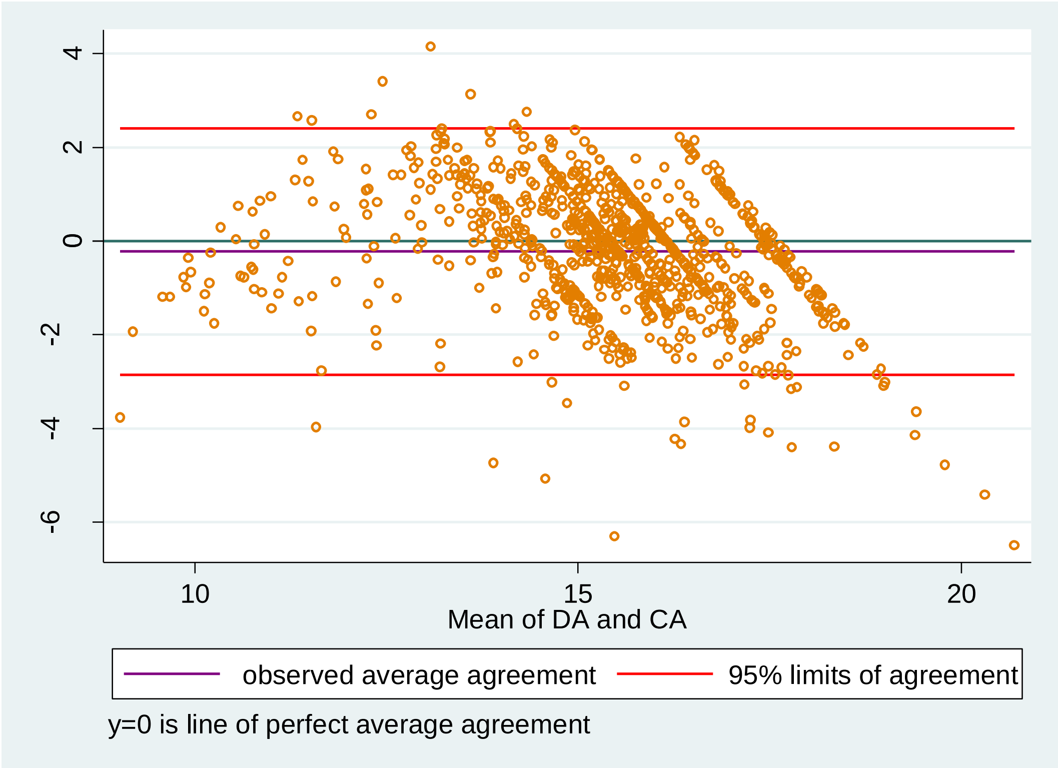


Figure 4.9 Bland - Altman plot showing measure of agreement between DA and CA for males >10 years using 8 stages.

The same pattern was observed for females (both under and over 10 years of age) and using 12 stages instead of 8.

Due to the difference between means for children under and over 10 years of age, further analysis was done to see if there was a particular age band where the change from positive to negative mean difference occurred. The sample was subdivided into two-yearly intervals by gender, and the DA compared to CA in a box plot (Figure 4.10). The bottom of each box represents the 25% percentile and the top is the 75% percentile, therefore the box represents the interquartile range, and the horizontal line through the box is the median. The whiskers indicate the upper and lower adjacent values and outside values are indicated by an asterisk. The horizontal red line on the box plot shows where the difference between DA and CA = 0. For males, the transition from positive to negative occurred between 9-10 years. This was the same for both staging systems. The box plot shows 9-10, 15-16 and 17-18 years with the negative difference between DA and CA, indicating that DA is underestimating age. The outliers are shown, with most being negative, meaning DA was underestimating age, particularly in the older age groups.

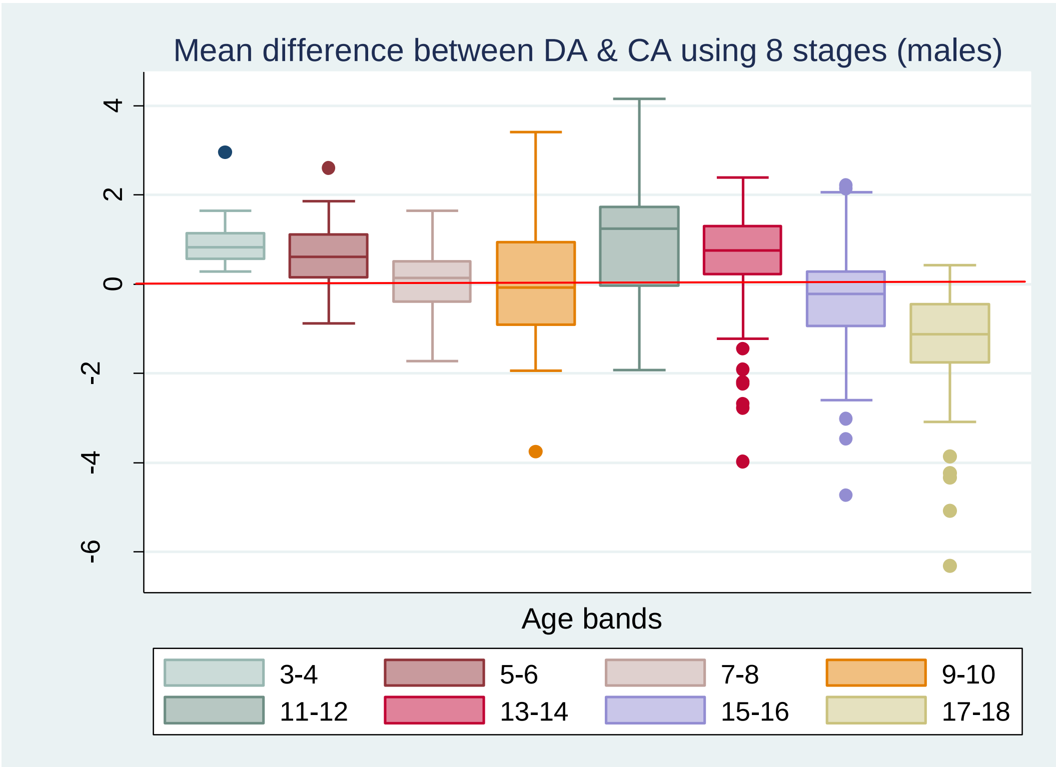


Figure 4.10 Box plot of mean difference between DA – CA by age band using 8 stages (males). Red line indicates difference DA – CA = 0.

For females, the transition from positive to negative values also occurred at 9-10 years (Figure 4.11). The mean difference between DA and CA was positive from 10 – 14 years and negative again afterwards, as shown by the red line in Figure 4.11. The widest interquartile range was for 9-10 and this age group also had the longest whiskers, along with 15-16 years. Most outliers were in the 11-12 and 15-16 age bands and the majority showing a negative mean difference between DA and CA (i.e. delayed DA).

This meant that there appeared to be a general trend of DA becoming more delayed in older children, when there were fewer developing teeth present. The SD of the difference was also not related to whether the mean CA-DA was positive or negative.

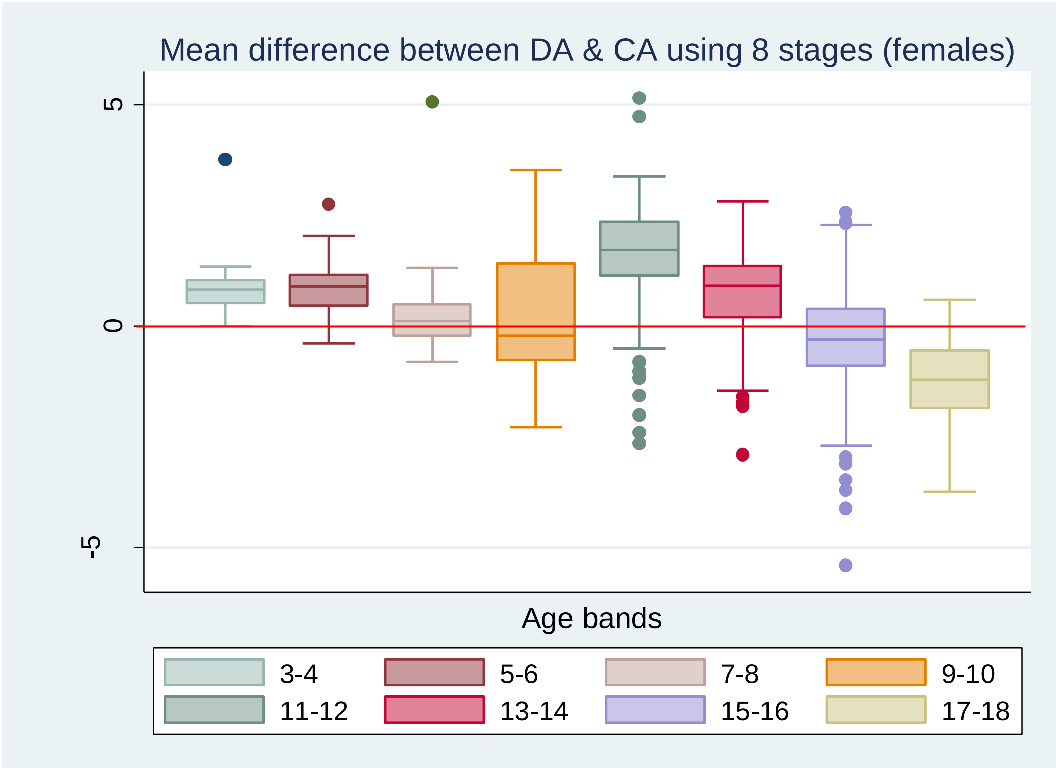


Figure 4.11 Box plot of mean difference between DA – CA by age band using 8 stages (females). Red line indicates difference DA – CA = 0.

The accuracy of DA estimation had been tested using 12 and 8 stages and there was no difference between using either staging system. As the 8 stages had better reproducibility, it was decided to use the 8 stage system only for the estimation of DA using the independent sample.

4.4.7 Estimating DA using the independent sample

There were 109 males (55%) and 91 females (45%) with an age range from 3.6 – 16.2 years. For the males, the mean difference between DA and CA was 0.5 years (SD 1.0 years), with 95% limits of agreement from 2.6 to -1.5 (range = 4.1 years), and a strong, positive association between DA and CA (r = 0.88). There were 91 females, with a mean difference between DA and CA of 0.7 years (SD 1.0 years). The 95% limits of agreement ranged from 2.6 to -1.2 years (range = 3.8 years) and a strong, positive association between CA and DA, with (r = 0.89).

For both males and females DA was greater than CA. This was in contrast to the DAA database subjects, where DA was less than CA. In addition, the mean difference for the test group was larger (-0.56 years for males and -0.77 years for females) compared to 0.13 years for males and 0.15 years for females for the DAA database. The SD for the independent group was also smaller than for the DAA database subjects.

4.4.8 Distribution of teeth

The stages were not evenly distributed in the DAA database, with stage H predominating. The exceptions were the third permanent molars, where there was a more even distribution of stages. This is illustrated graphically by the bar chart showing the number of teeth per stage for the UL1, LL5 and LL8, with the sexes combined (Figure 4.12). These teeth were chosen as they represent early, intermediate and late developing teeth, with the difference in the spread of teeth per stage. There were no subjects with teeth at stage A or B for the UL1, as these stages develop soon after birth, and no radiographs were available at that age.

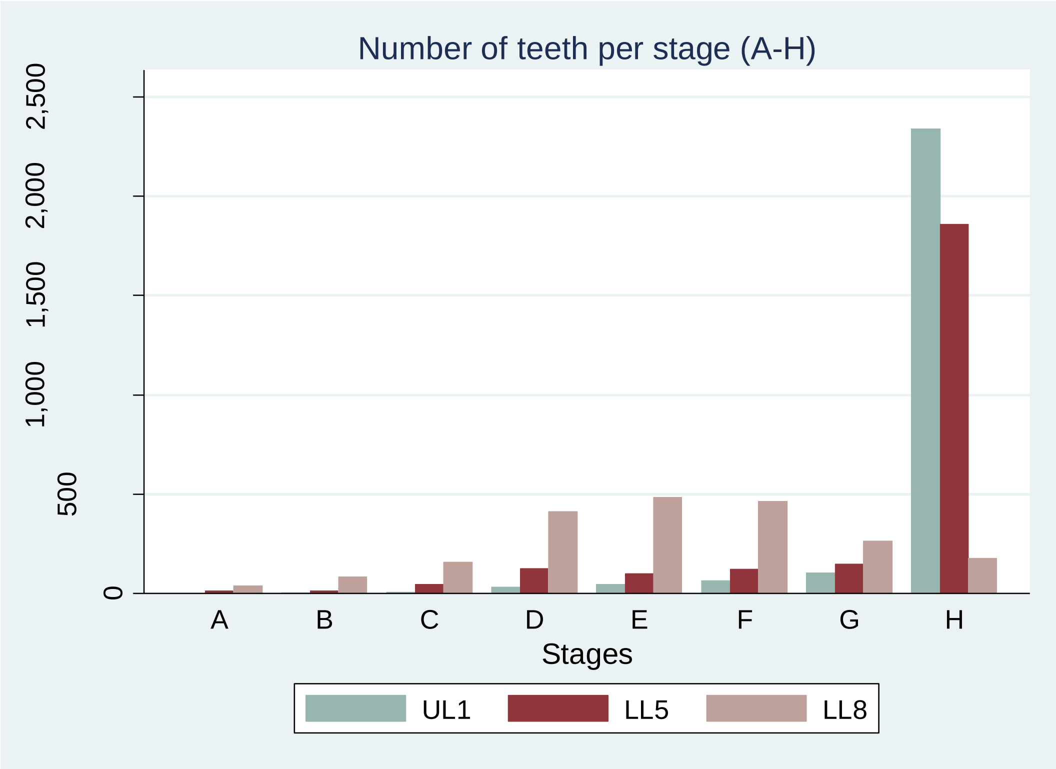
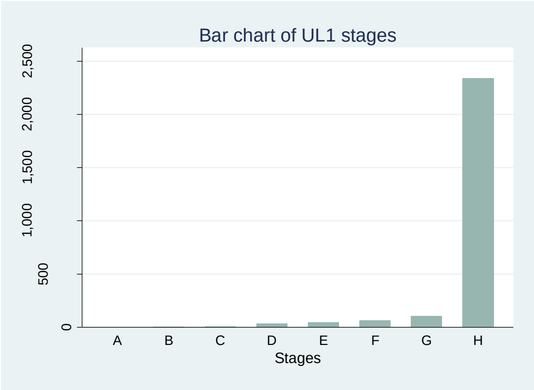
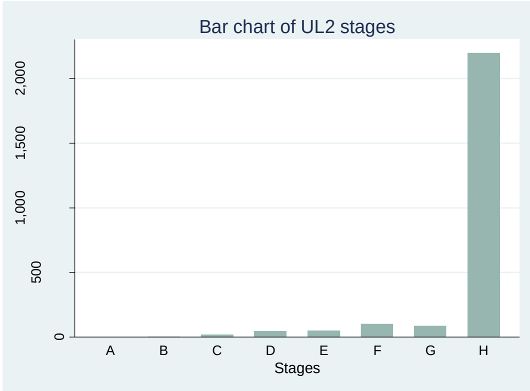
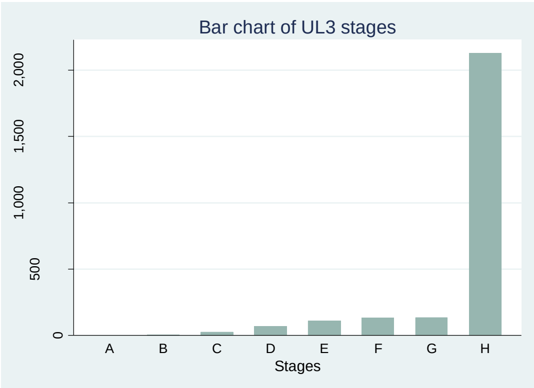


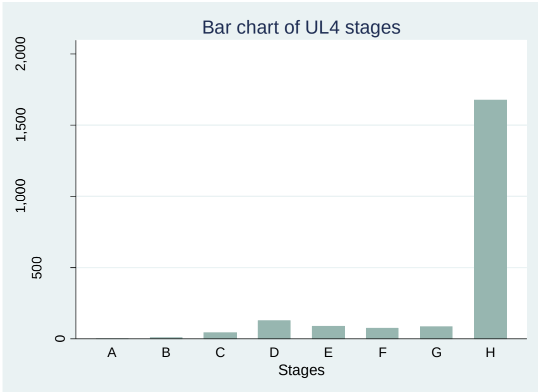
Figure 4.12 Bar chart of number of teeth by stage (A-H) for UL1, LL5 and LL8.

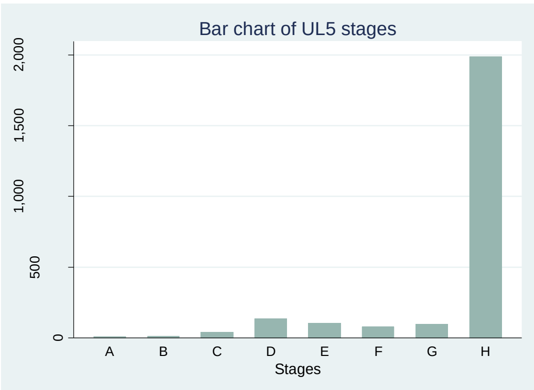
The distribution of n-tds for each of the 18 teeth assessed (both genders combined) is shown in Figure 4.13.

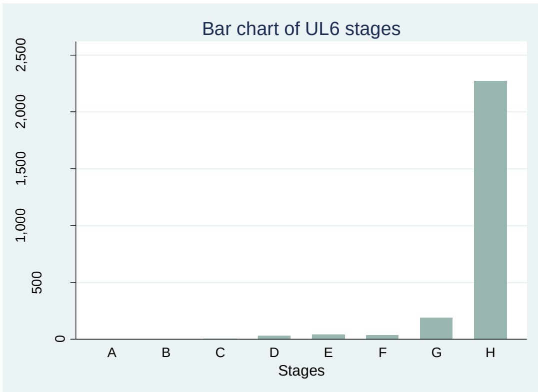

Bar chart of UL1 stages
0
500
1,000
1,500
2,000
2,500
A B C D E F G H
Stages

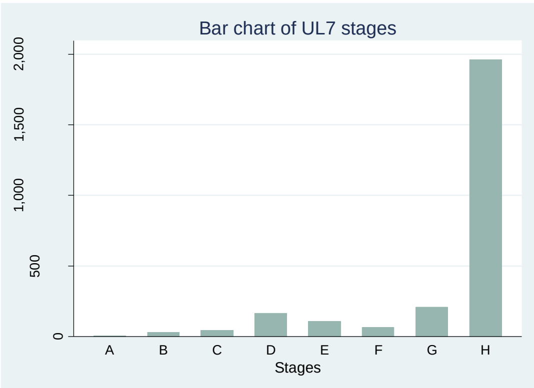

Bar chart of UL2 stages
0
500
1,000
1,500
2,000
A B C D E F G H
Stages

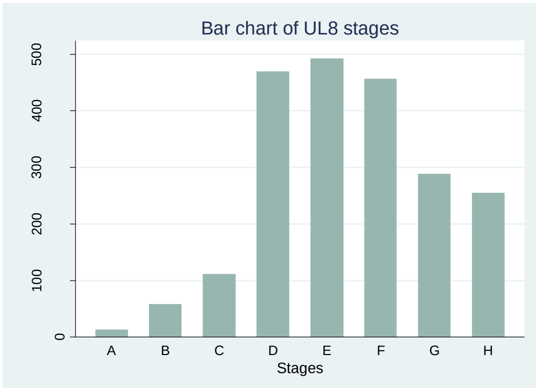

Bar chart of UL3 stages
0
500
1,000
1,500
2,000
A B C D E F G H
Stages

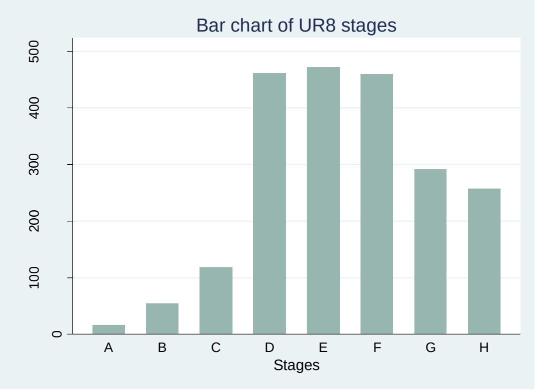

Bar chart of UL4 stages
0
500
1,000
1,500
2,000
A B C D E F G H
Stages

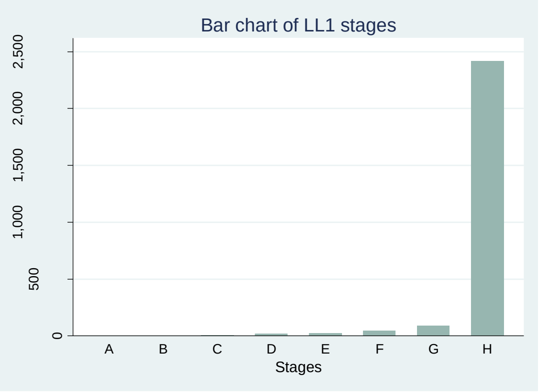

Bar chart of UL5 stages
0
500
1,000
1,500
2,000
A B C D E F G H
Stages

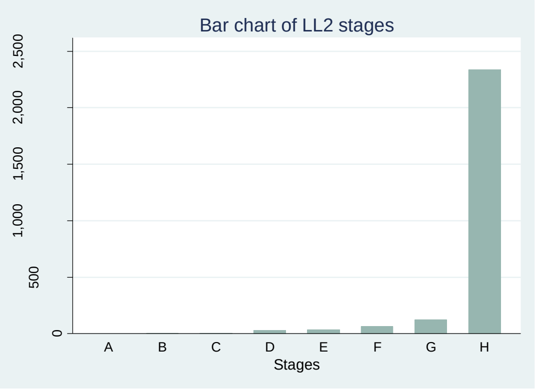

Bar chart of UL6 stages
0
500
1,000
1,500
2,000
2,500
A B C D E F G H
Stages

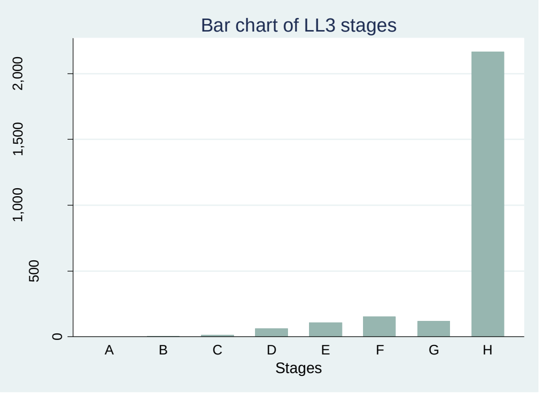

Bar chart of UL7 stages
0
500
1,000
1,500
2,000
A B C D E F G H
Stages

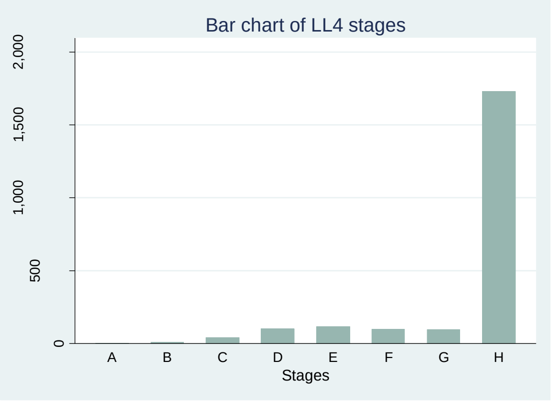

Bar chart of UL8 stages
0
100
200
300
400
500
A B C D E F G H
Stages

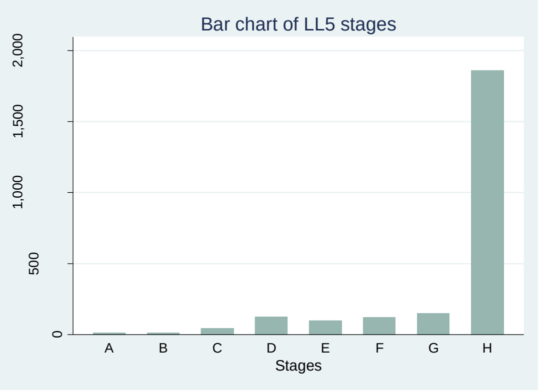

Bar chart of UR8 stages
0
100
200
300
400
500
A
B
C
D
E
F
G
H
Stages


Bar chart of LL1 stages
0
500
1,000
1,500
2,000
2,500
A
B
C
D
E
F
G
H
Stages


Bar chart of LL2 stages
0
500
1,000
1,500
2,000
2,500
A
B
C
D
E
F
G
H
Stages


Bar chart of LL3 stages
0
500
1,000
1,500
2,000
A
B
C
D
E
F
G
H
Stages


Bar chart of LL4 stages
0
500
1,000
1,500
2,000
A
B
C
D
E
F
G
H
Stages


Bar chart of LL5 stages
0
500
1,000
1,500
2,000
A
B
C
D
E
F
G
H
Stages

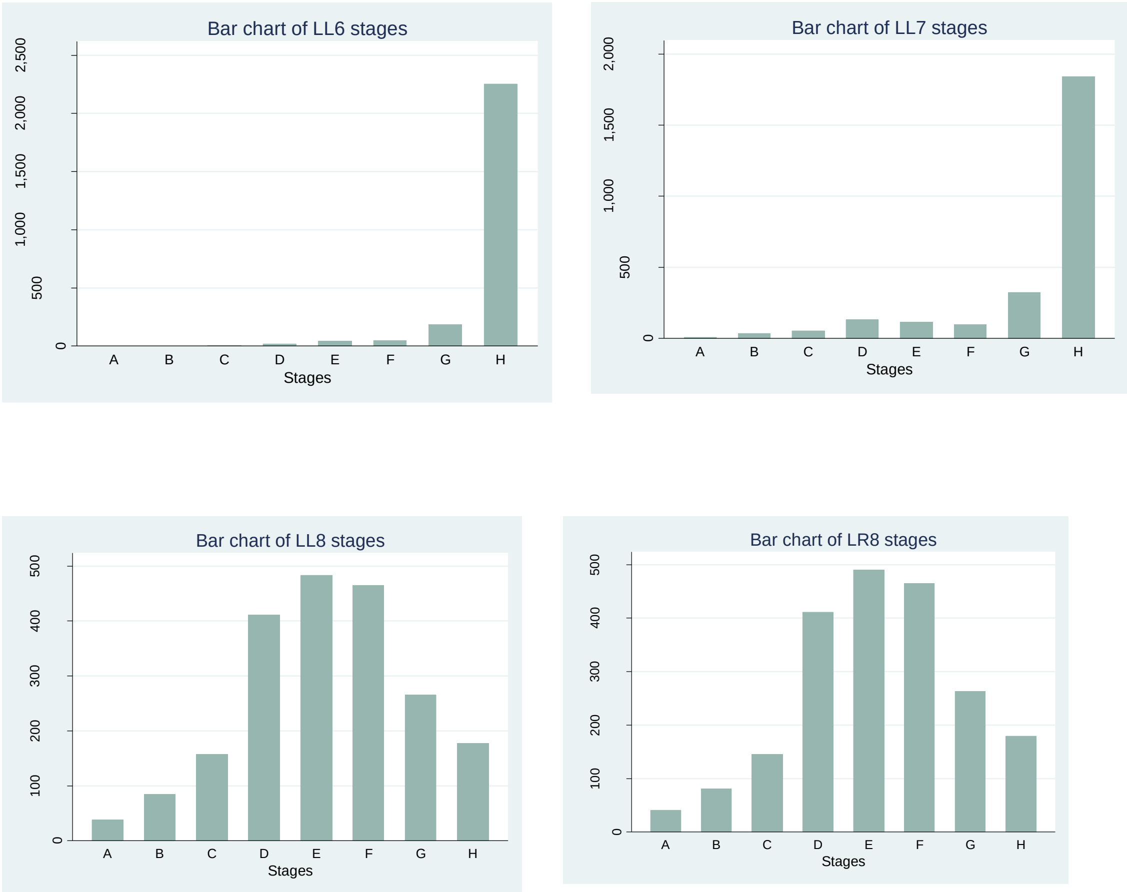


Figure 4.13 n-tds distribution for all teeth (genders combined).

Figure 4.13 illustrates that apart from the third permanent molars, the prevailing stage for other teeth was stage H, which is not used in methods of DA estimation, although for the later developing canine, premolars and second permanent molars other stages were represented.

The distribution of mean age of attainment for the same 3 teeth is shown in Figure 4.14. For all teeth, the mean age of attainment per stage increased with increasing age, as expected, with UL1 earlier than LL5, which was earlier than LL8. This difference is less marked for stage H, but this needs to be viewed with caution, as there is no upper limit for this stage and therefore was dependent on the number of older subjects in the DAA database.

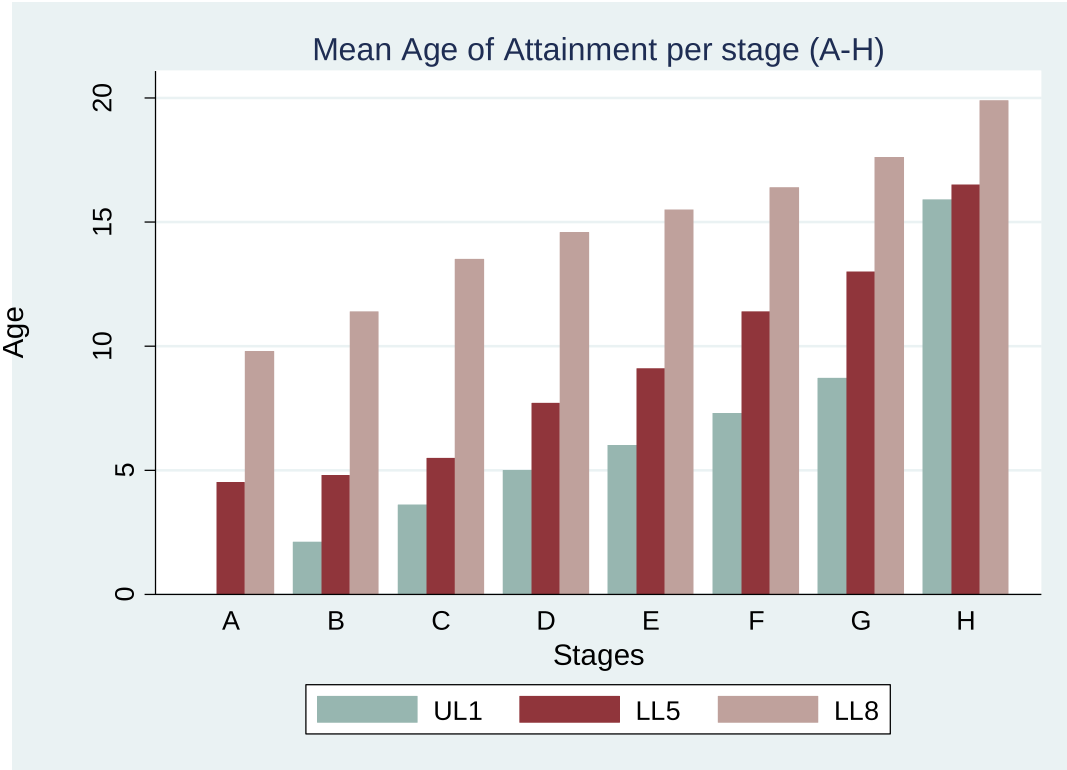


Figure 4.14 Bar chart of mean age of attainment by stage (A-H) for UL1, LL5 and LL8.

The bar chart of the standard deviation for the 3 teeth illustrates considerable variation by stage and by tooth (Figure 4.15). The SD was not related to the *n-tds*, as a larger number of subjects per stage did not correspond to a smaller value in SD. The LL8 showed the most variation across the eight stages, with an average SD of 1.9 years. Stage H showed the largest values of SD, but this was due to the large range of values and no upper limit.

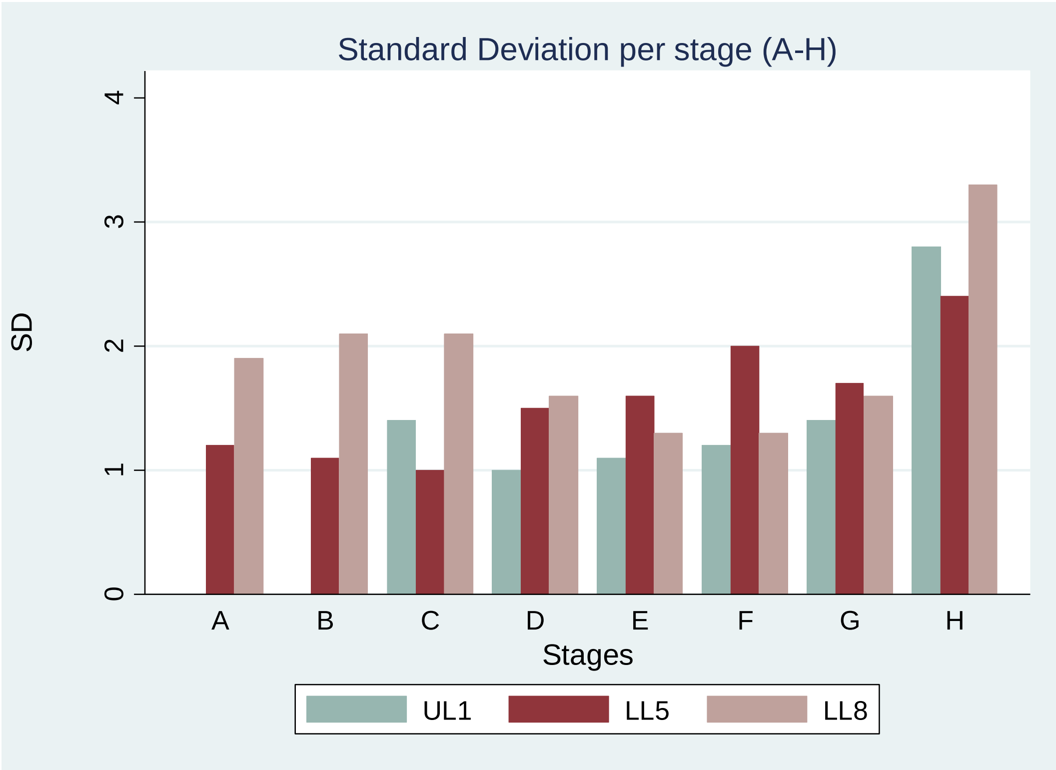


Figure 4.15 Bar chart of the standard deviation by stage (A-H) for UL1, LL5 and LL8.

The SD of age of attainment was plotted against the mean age of attainment for males (Figure 4.16) and females (Figure 4.17). The SD increases with increasing mean age of attainment, with the third permanent molars having the largest SD and hence greatest variation of the TDS. There is a spike in males at around 12 years of age, and for females from 10 -14 years of age, which relates to the onset of puberty, when the third permanent molars are developing, and developmental age is most variable.

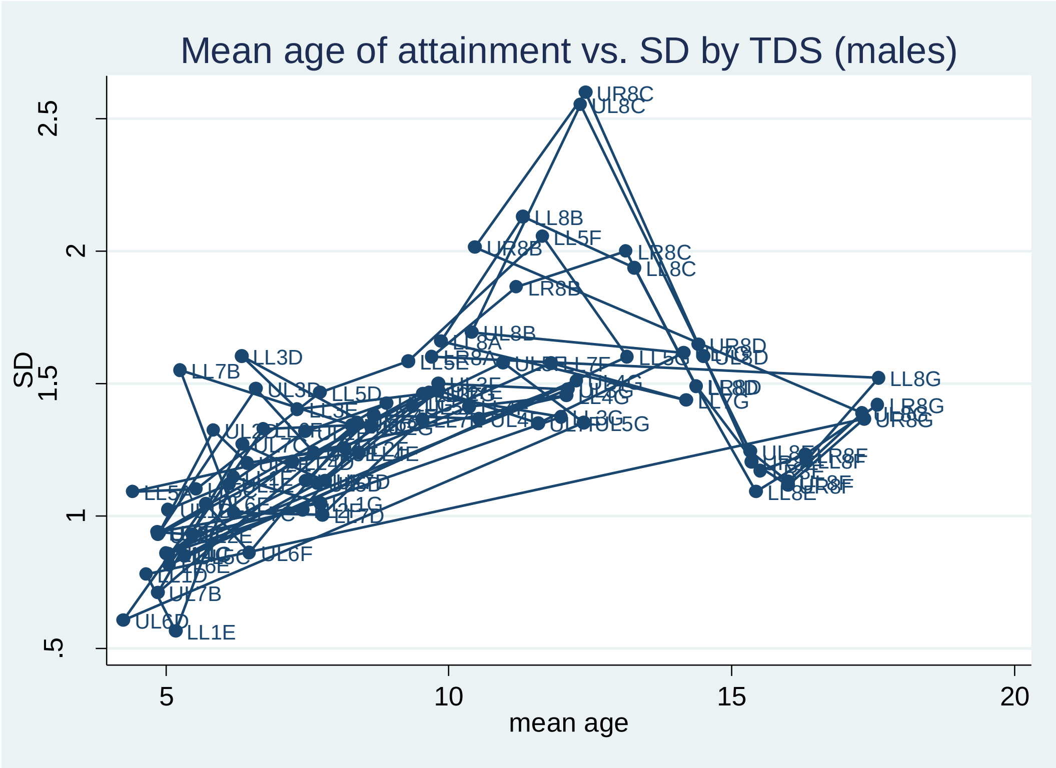


Figure 4.16 Scatter graph of mean age vs. SD by TDS for males.

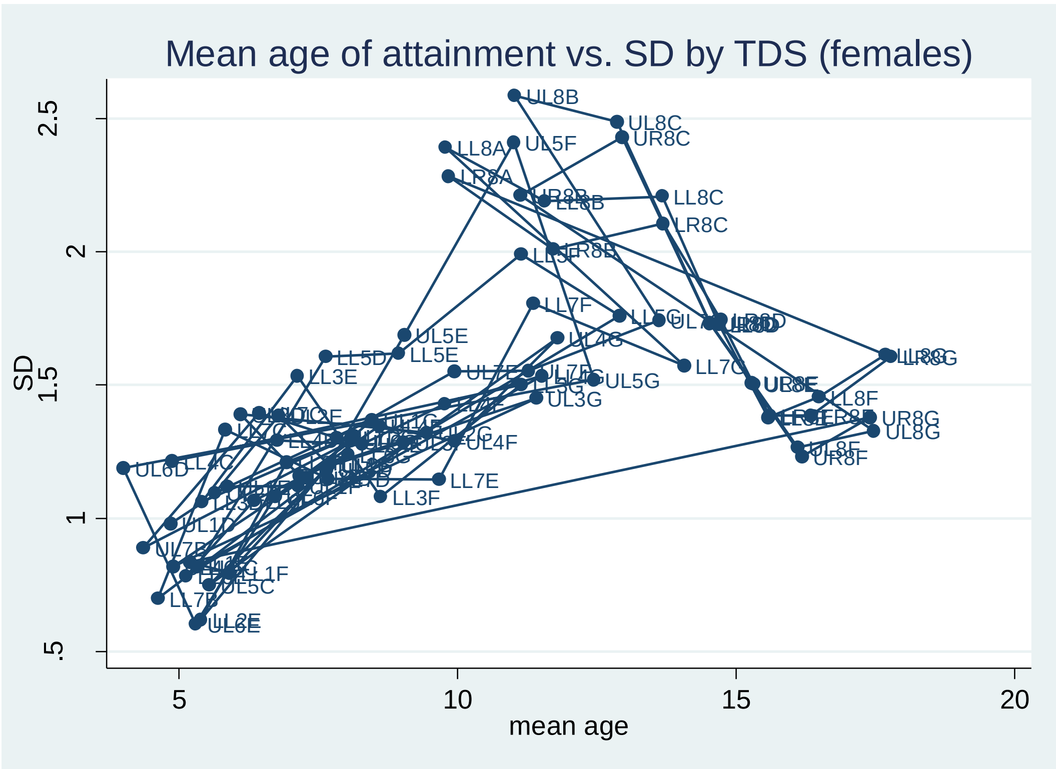


Figure 4.17 Scatter graph of mean age vs. SD by TDS for females.

Due to the variation seen in SD for the different teeth, the individual TDS were investigated to see if the distribution was related to the n-tds.

4.4.9 Distribution of individual TDSs

The distribution of each TDS was assessed visually using histograms, and tested for normality using the Shapiro-Wilk Test. This is illustrated by comparing the histograms for the upper right permanent third molar stage D for males (UL8D) where *n-tds* = 201 (Figure 4.18), and the upper left second permanent molar stage E for females (UL7E) where *n-tds* = 45 (Figure 4.19). The blue line in the histogram for UL8F shows the normal distribution, and it can be seen that the distribution for UL8F follows this closely. The Shapiro-Wilk test showed the distribution was not significantly from normal (p= 0.12). In contrast, UL7E shows a skewed distribution to the right, and the Shapiro-Wilk test for UL7E confirmed that the data was non-normally distributed (p=0.002).

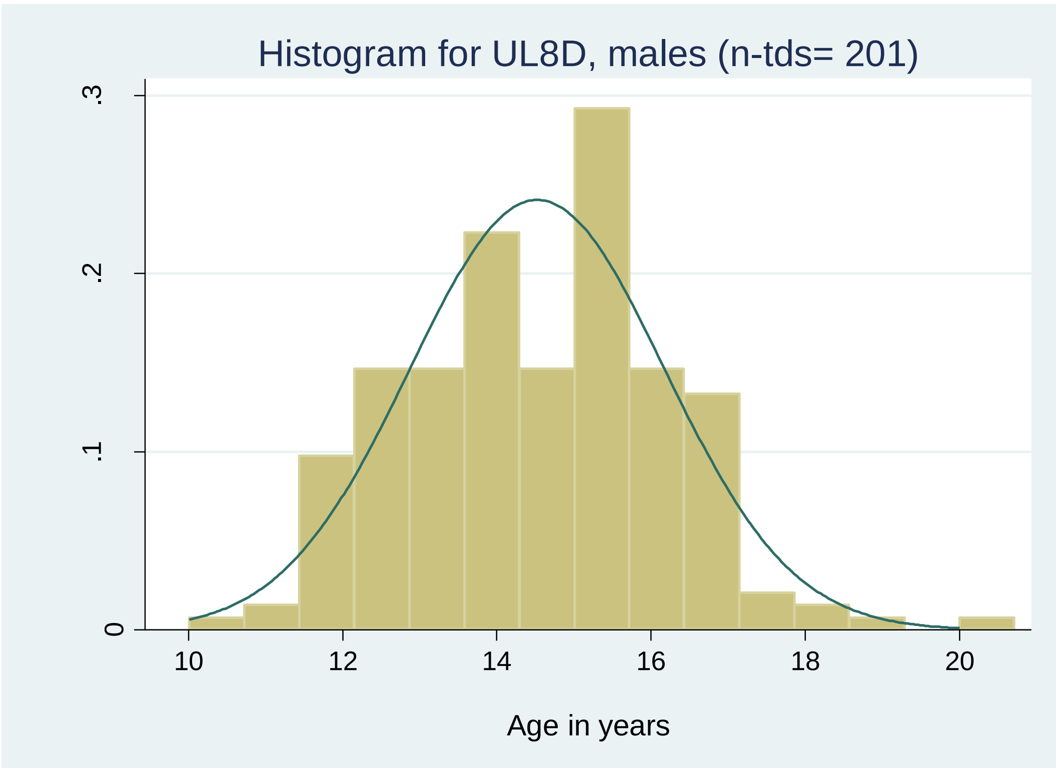


Figure 4.18 Histogram of frequency distribution for UL8D for males, showing normal curve.

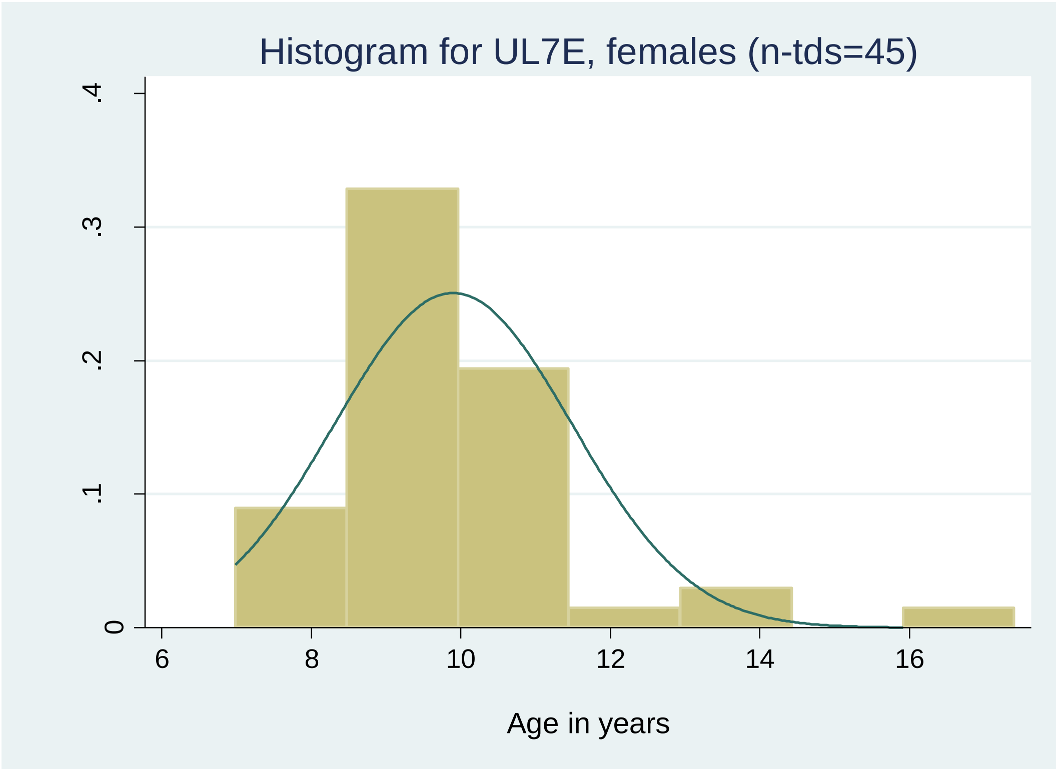


Figure 4.19 Histogram of frequency distribution for UL7E for females, showing normal curve

The Shapiro-Wilk test was applied to all TDS, using the 8 stage system for males and females separately (Appendix 12), for stages A-G (significant p values are shown in italics, empty cells indicate no values were available). For males, the upper teeth were all normally distributed for all stages except the UL2, UL6, UL8 and UR8. In the lower jaw, the only tooth normally distributed across all stages was the LL3. In contrast, for females the only upper teeth normally distributed were the UL2 and UL6, with the LL1, LL2 and LL6 normally distributed among the lower teeth.

There were 32 TDSs (25%) which were not normally distributed for males, and 38 TDSs (24%) for females. The majority of non-normally distributed teeth were skewed to the right (as shown in Figure 4.19), the only exceptions in females being the UL7D, UL8D (Figure 4.20) and LL7D in males which were skewed to the left. This suggested that stage D had more subjects with younger ages of attainment than other stages; however further investigation of other non-normal stage D's (LL5D & LL8D) showed that they were also skewed to the right. No tooth was normally distributed for both genders and all stages, with the third permanent molars showing the most non-normal distributions. This was despite the third permanent molars having the largest *n-tds*, and again demonstrated that normal distribution was dependent on the variability of the TDS and any outliers, and not the *n-tds*.

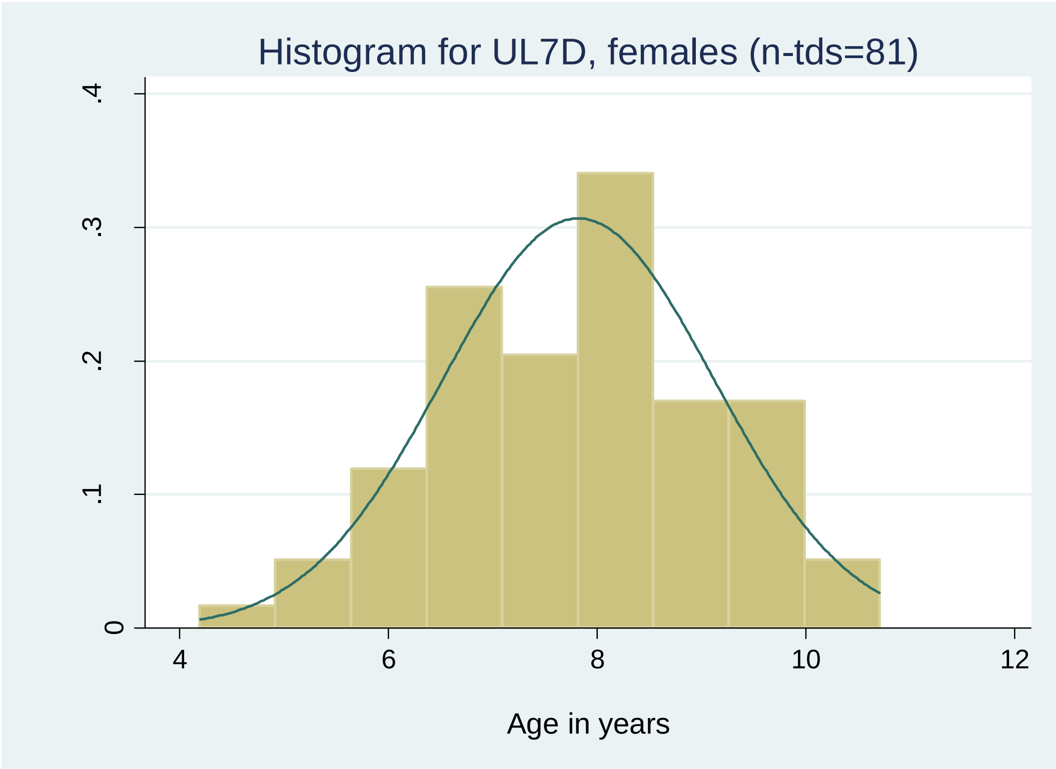


Figure 4.20 Histogram of frequency distribution for UL7D for females, showing normal curve.

Stage H was considered separately, as it has no upper limit and tails off to the right, as shown in Figure 4.21 for the LL1H males (*n-tds* = 1063). The distribution is clearly not normally distributed and several outliers are clearly visible over 30 years of age, and the Shapiro-Wilk test was highly statistically significant ($p < 0.0001$).

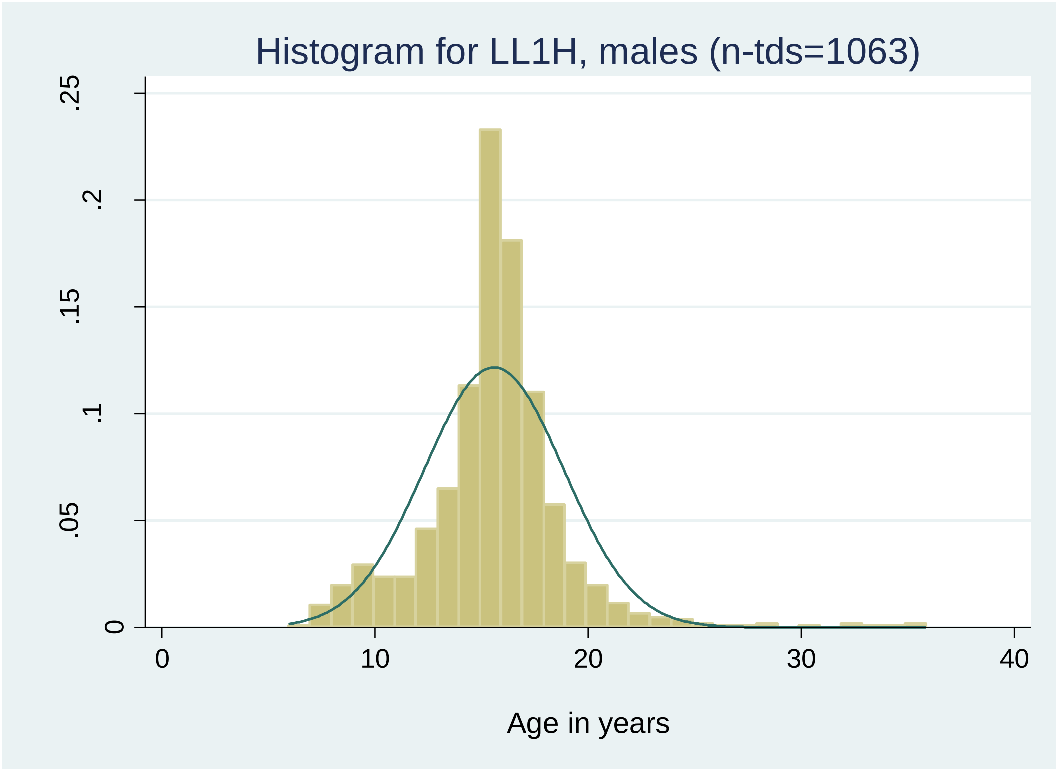


Figure 4.21 Histogram of frequency distribution for LL1H for males, showing normal curve.

4.4.10 Censoring stage H

The median ages of attainment of stage H for all teeth were calculated before and after censoring (Table 4.7), as described in section 4.1.7. The median ages for the early developing teeth were set artificially high; by censoring the data a more reliable estimate of the median age was obtained. For example, the median age of attainment of stage H for the LL1 was 15.7 years for both genders, this decreased to 8.8 years after censoring. The effect of censoring was less marked for the later developing teeth (the third permanent molars) e.g. the UL8 stage H in females reduced from 19.2 to 18.9 years. The median age for females was generally less than males, as females matured earlier than males. The exceptions were the UL5, UR8, LL1 and LL8, where the median age was the same for both genders.

Upper tooth	Gender	Median age of attainment (years)		Lower tooth	Gender	Median age of attainment (years)	
		Before censoring	After censoring			Before censoring	After censoring
UL1	Males	15.7	11.4	LL1	Males	15.7	8.8
	Females	15.8	10.2		Females	15.7	8.8
UL2	Males	15.8	12.4	LL2	Males	15.2	10.3
	Females	15.8	10.7		Females	15.7	9.8
UL3	Males	15.9	15.1	LL3	Males	15.9	13.7
	Females	15.9	14.5		Females	15.8	13.2
UL4	Males	15.9	14.5	LL4	Males	15.9	13.7
	Females	15.9	14.4		Females	15.8	13.2
UL5	Males	16.0	14.5	LL5	Males	16.1	15.3
	Females	15.9	14.5		Females	16.0	14.9
UL6	Males	15.7	11.3	LL6	Males	15.7	10.3
	Females	15.8	10.2		Females	15.8	9.9
UL7	Males	16.1	15.8	LL7	Males	16.2	15.9
	Females	16.0	15.3		Females	16.1	15.4
UL8	Males	19.3	19.1	LL8	Males	19.7	19.3
	Females	19.3	19.0		Females	19.7	19.3
UR8	Males	19.4	18.9	LR8	Males	19.7	19.5
	Females	19.2	18.9		Females	19.8	19.2

Table 4.7 Median ages of attainment for stage H before and after censoring.

4.4.11 Time interval between stages

Inevitably the mean ages of attainment for each TDS increased with increasing stage, i.e. stage B was greater than stage A etc as demonstrated for the UL5 in males (Figure 4.22). Bar charts of the mean age of attainment by TDS showed that the height of the bars per stage did not increase evenly, and it was unclear if the time interval between stages was equally spaced.

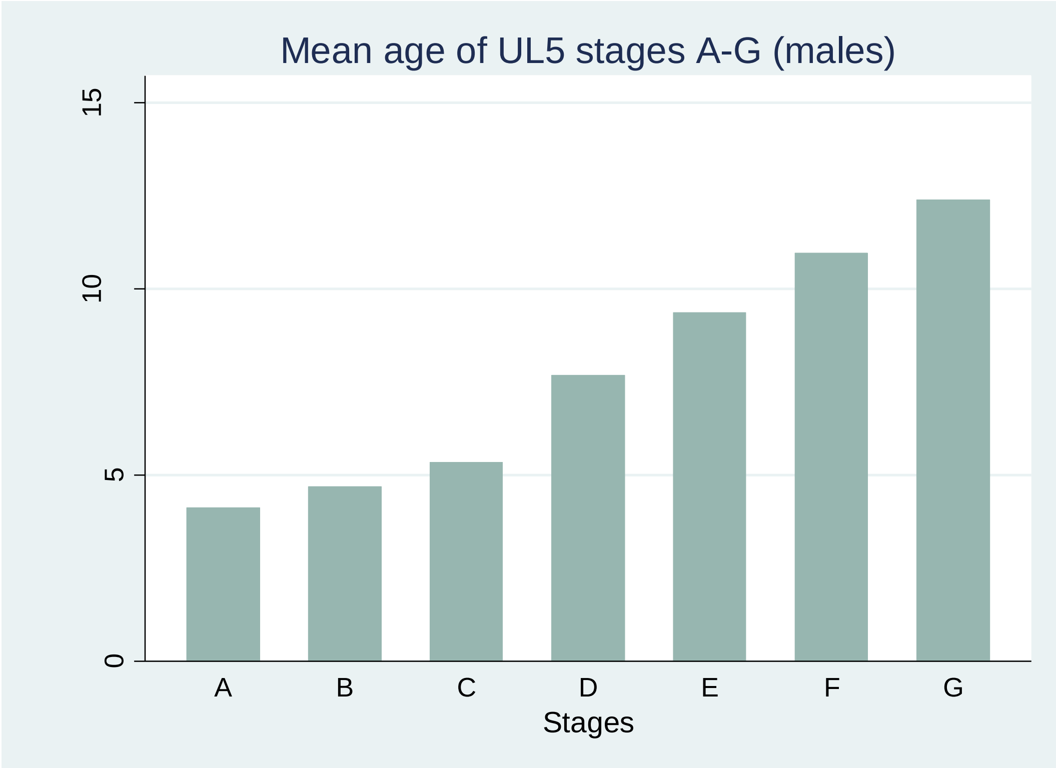


Figure 4.22 Mean age of attainment by stage for UL5 in males.

The mean age of attainment of each TDS was used to calculate the average time between stages for males and females, e.g. the time interval for A-B was the mean age of attainment for stage B minus the mean age for stage A (Table 4.8). A blank cell indicated that there were no teeth in either stage, therefore calculations of time interval were not possible. For the early developing teeth, incisors and first molars, the longest interval between stages was F-G (range = 1.2 to 1.9 years). In the intermediate developing teeth, canines and premolars, the largest interval was C-D (range = 0.3 to 2.4 years), whereas D-E and F-G were the largest for the second permanent molars. In the case of the late developing teeth, third permanent molars, B-C was the longest interval. These trends were observed in both genders, and are illustrated for the upper seven permanent teeth, excluding third permanent molars (fig 4.23).

Tooth	Gender	Difference between mean age for stages in years					
		A-B	B-C	C-D	D-E	E-F	F-G
UL1	Males			0.3	1.1	1.4	1.4
	Females		1.0	1.9	1.1	1.2	1.5
UL2	Males		1.6	0.7	0.7	1.8	1.5
	Females		1.3	1.8	1.1	0.9	1.7
UL3	Males			1.6	1.1	2.2	2.3
	Females		1.2	1.9	1.0	1.9	2.4
UL4	Males		0.6	2.4	1.0	2.0	1.7
	Females	1.5	0.4	2.4	1.4	1.3	1.9
UL5	Males	0.5	0.6	2.3	1.6	1.6	1.5
	Females	0.9	1.4	1.8	1.5	1.6	1.8
UL6	Males				1.3	0.8	1.9
	Females			0.5	1.3	1.2	1.6
UL7	Males	0.2	1.4	1.5	2.0	1.8	2.5
	Females	0.6	1.9	1.6	2.0	1.5	2.1
LL1	Males			1.3	0.5	0.9	1.6
	Females			0.4	1.4	0.8	1.7
LL2	Males		1.9	0.4	0.5	2.1	1.2
	Females			1.3	0.8	1.5	1.3
LL3	Males		0.9	1.8	1.1	2.2	2.5
	Females		0.9	1.4	1.6	1.6	2.5
LL4	Males		1.2	2.2	1.2	2.1	1.6
	Females	0.7	1.1	1.9	1.6	1.4	1.8
LL5	Males	0.3	0.8	2.2	1.4	2.6	1.4
	Females	0.2	0.8	2.0	1.4	2.2	1.6
LL6	Males				0.6	1.6	1.6
	Females				1.7	1.1	1.9
LL7	Males	0.6	1.1	1.5	1.8	2.3	2.4
	Females	1.5	1.0	2.1	1.9	1.8	2.6
UL8	Males	1.7	1.9	2.1	0.8	0.7	1.3
	Females	1.7	2.2	1.3	0.7	0.8	1.4
UR8	Males	0.8	2.2	1.9	0.9	0.7	1.3
	Females	1.7	2.2	1.3	0.7	0.9	1.2

Tooth	Gender	Difference between mean age for stages in years					
		A-B	B-C	C-D	D-E	E-F	F-G
LL8	Males	1.3	2.1	1.0	1.0	0.9	1.3
	Females	1.7	2.3	0.8	1.0	0.9	1.2
LR8	Males	1.5	2.1	1.1	1.1	0.8	1.3
	Females	1.8	2.1	0.8	1.0	0.7	1.5

Table 4.8 Difference between adjacent stages (A-G) for both genders.

There was no clear pattern of increasing time interval being associated with later developing stages or differences between genders, for either particular teeth or TDS.

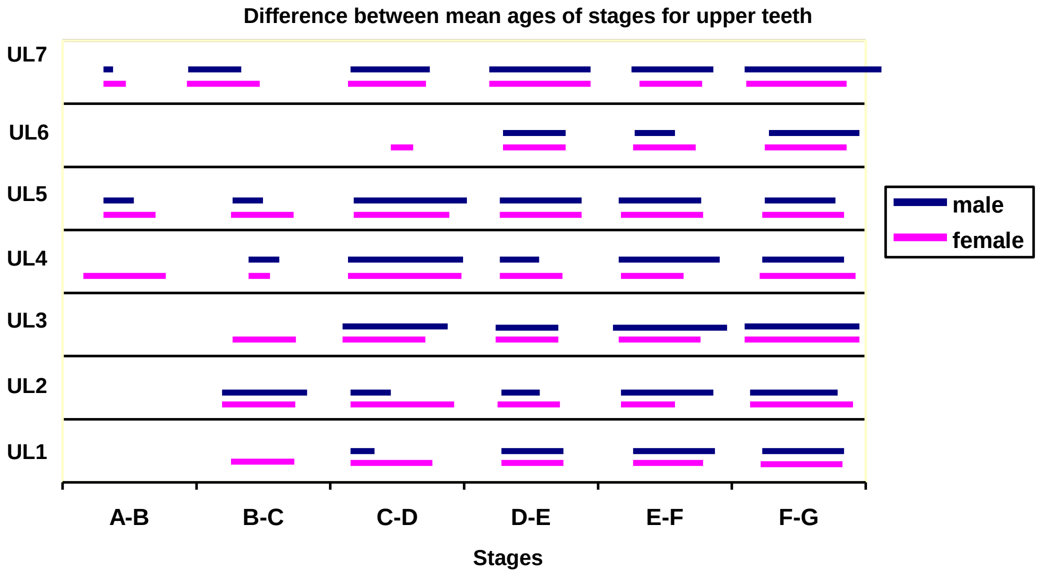


Figure 4.23 Time interval of difference between mean ages for upper teeth, both genders.

The time span for stages was shown as box plots for the UL5 and LL8 (Figure 4.24 & 4.25 respectively). The interquartile range for males was longest for stage F and had the widest whiskers at approximately 7 years, whilst for females, the whiskers which represent the upper and lower adjacent values, were around 5 years. In contrast, for the LL8 the earlier stages had the widest interquartile ranges (in particular stage B for males and stage C for females).

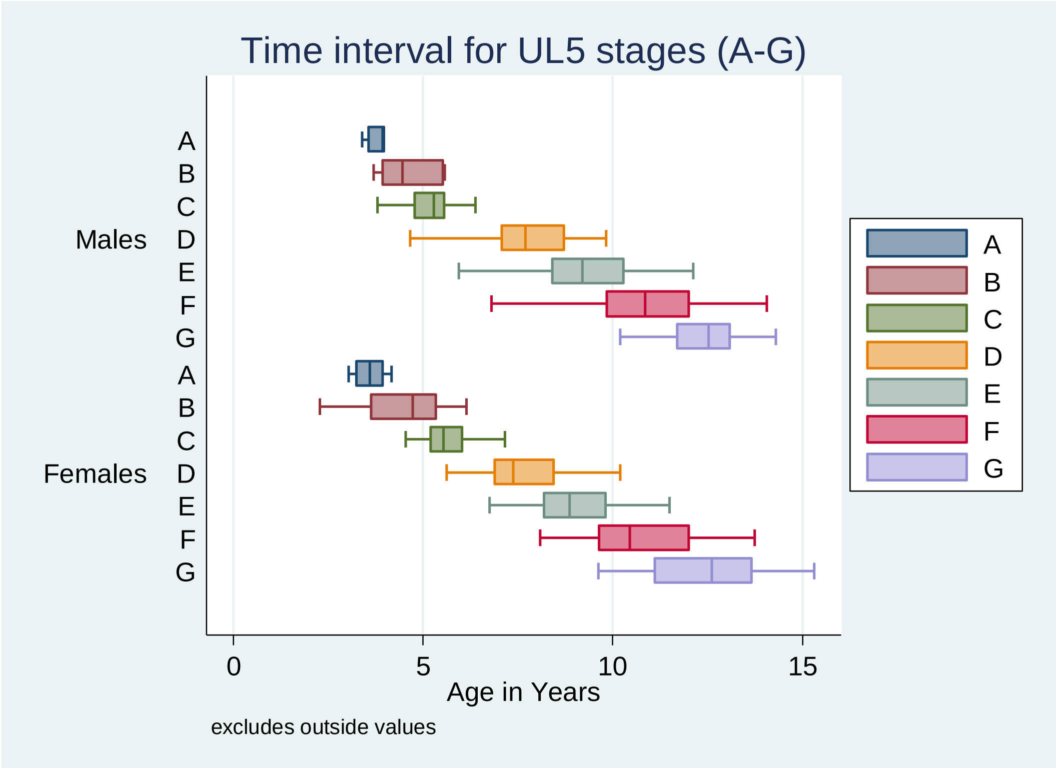


Figure 4.24 Time interval for UL5 stages (A-G) both genders.

The general pattern of increasing intervals with later stages for males and females for the UL5 is illustrated (Figure 4.24). Conversely, the decreasing time interval with later stages of the LL8 is shown (Figure 4.25).

The time interval between 8 and 12 stages was also compared, as it was expected that the time span for 12 stages was less than 8 stages. The average time between stages for males and females was used to calculate the mean age of attainment of each TDS, as before, for both staging systems. The average time span between two consecutive TDS using 8 stages was 1.4 years for both genders, whereas the time taken using 12 stages was 1.0 years.

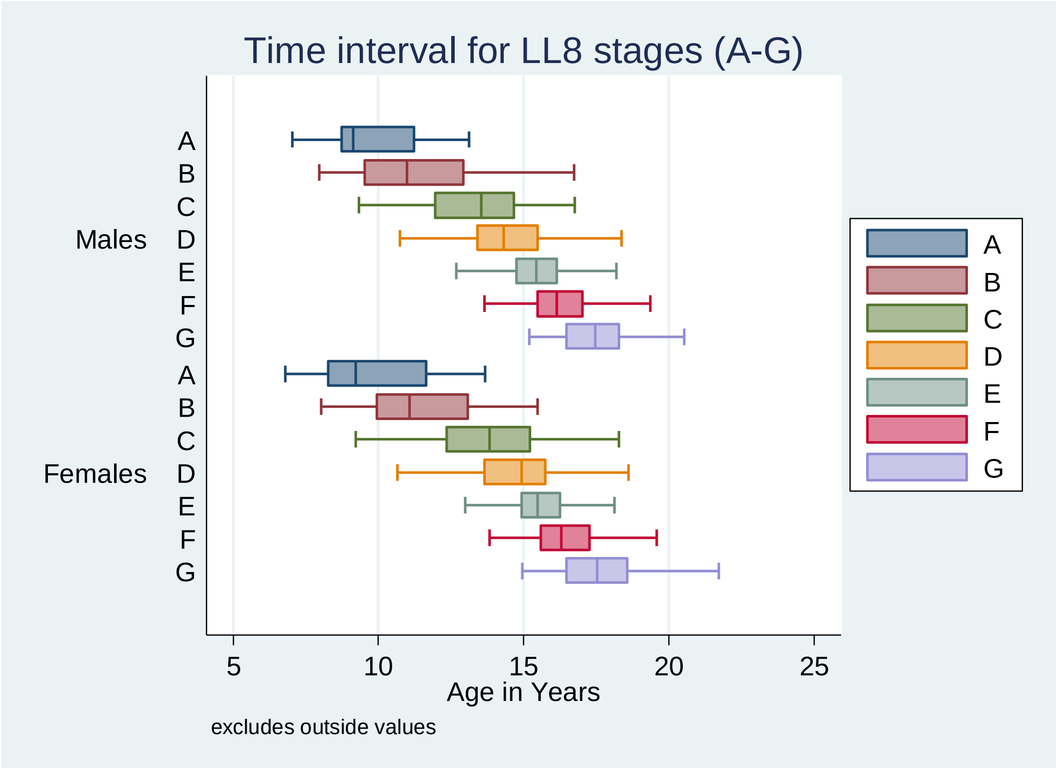


Figure 4.25 Time interval for LL8 stages (A-G) both genders.

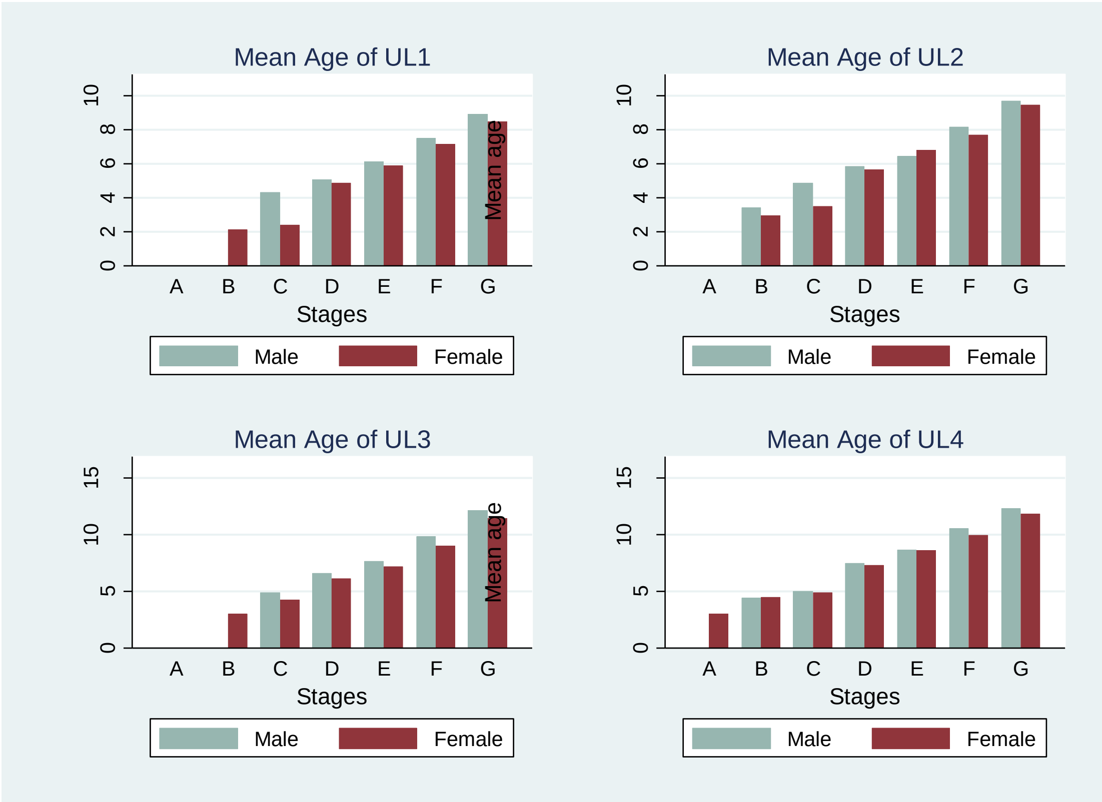
4.4.12 Effect of gender

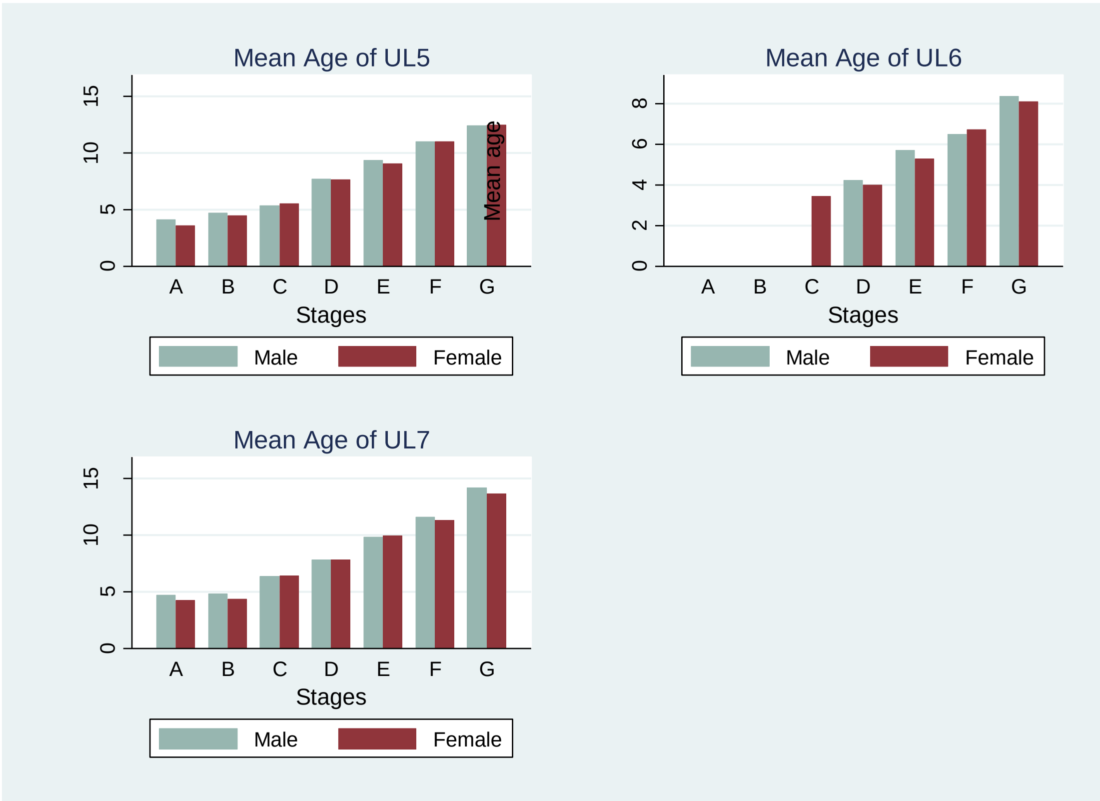
The descriptive statistics for the LL7 using the 8 stages and comparisons between genders are listed in Table 4.9. Although the number of subjects for the LL7 was large (n=761), broken down by gender and TDS the numbers for earlier stages were small. The mean age of attainment for females was generally earlier than for males (except stage E), although no stage was significantly different between males and females.

Tooth (N=761)	Gender	n-tds	mean	SD	Mean difference between males and females	p-value	95% CI of difference
LL7A	Male	4	4.3	0.5	0.6	0.4	-1.0 to 2.2
	Female	3	3.7	1.1			
LL7B	Male	23	5.2	1.5	0.6	0.2	-0.3 to 1.5
	Female	12	4.6	0.7			
LL7C	Male	33	6.2	1.0	0.4	0.2	-0.2 to 1.0
	Female	21	5.8	1.3			
LL7D	Male	67	7.8	1.0	0.1	0.6	-0.3 to 0.4
	Female	65	7.7	1.2			
LL7E	Male	65	9.5	1.4	-0.1	0.4	-0.7 to 0.3
	Female	50	9.7	1.1			
LL7F	Male	53	11.8	1.6	0.5	0.2	-0.2 to 1.2
	Female	43	11.3	1.8			
LL7G	Male	154	14.2	1.4	0.1	0.5	-0.2 to 0.4
	Female	168	14.1	1.6			

Table 4.9 Descriptive statistics for LL7 TDS by gender with results in years and p values of paired t-test.

This comparison was repeated for other teeth. Females developed faster than males for 92% of TDS for all teeth (excluding third permanent molars), the mean age of attainment being less for females than for males (Figure 4.26). For the third permanent molars males were younger for all stages, indicating that they were maturing faster then females (Figure 4.27).


Mean Age of UL1
Mean Age of UL2
Mean Age of UL3
Mean Age of UL4
Mean age
Stages
A B C D E F G
Male
Female


Mean Age of UL5
Mean Age of UL6
Mean Age of UL7
Mean age
Stages
A B C D E F G
Male
Female

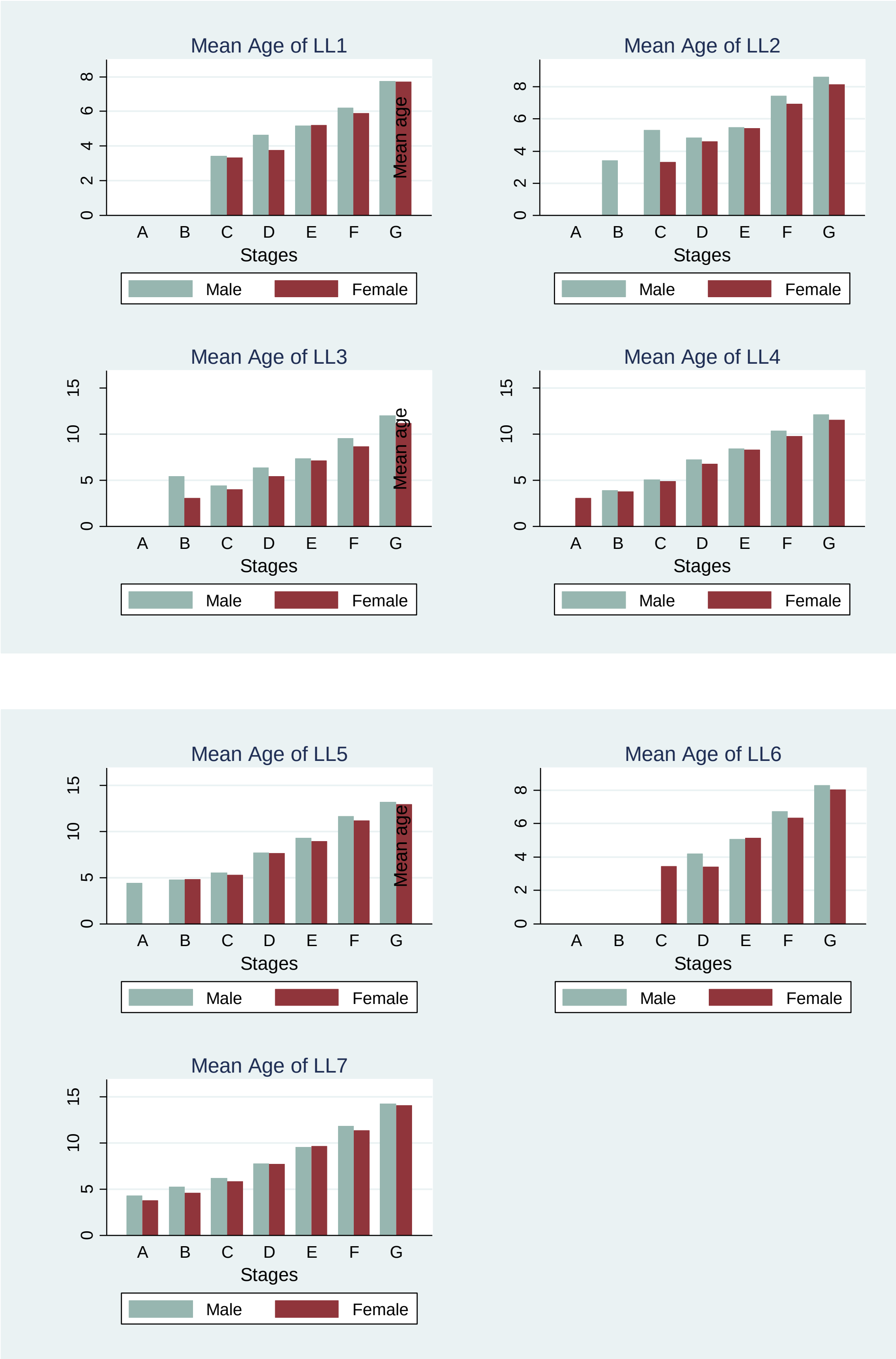


Figure 4.26 Mean age of attainment for all upper and lower permanent teeth (excluding third permanent molars) by gender

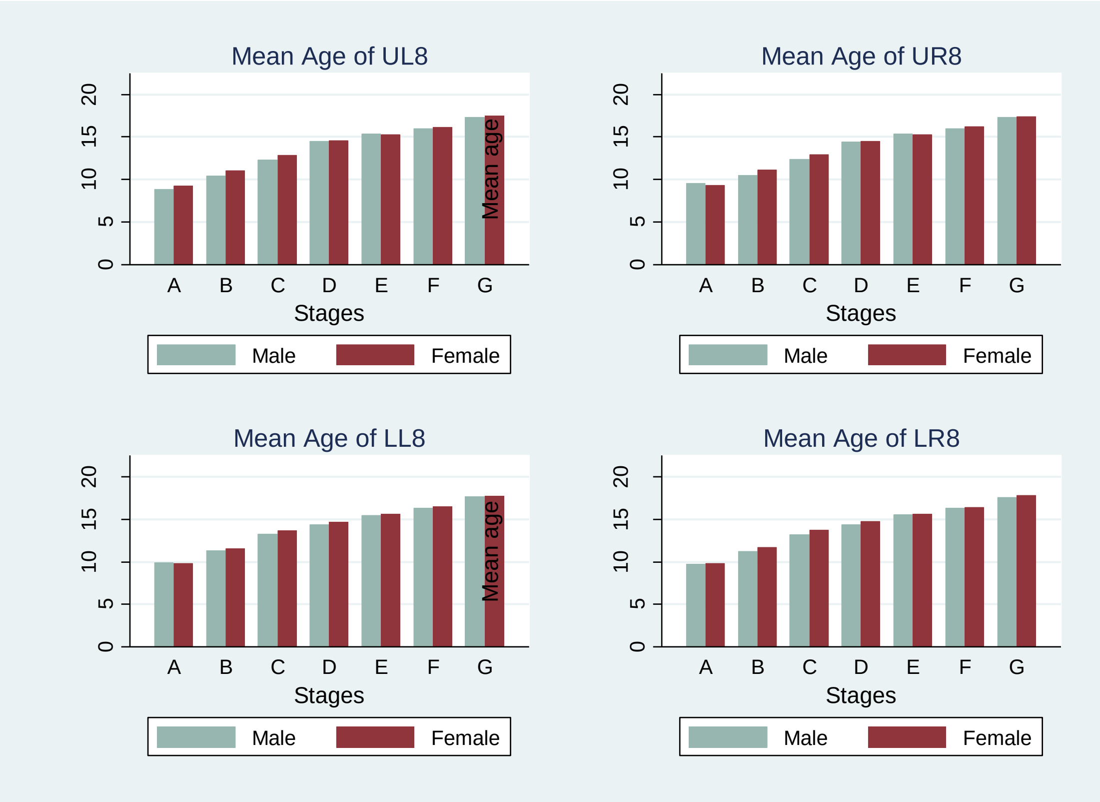


Figure 4.27 Mean age of attainment for upper and lower permanent third permanent molars by gender

The difference in mean age in years between genders was tested for significance for the third permanent molars, as shown for the LL8 (Table 4.10). Although males were younger than females for all stages, except stage A, the difference between sexes was small and not significant. The other 3 third permanent molars similarly showed no difference.

Tooth (N=1903)	Gender	n-tds	mean	SD	Mean difference between males and females	p-value	95% CI of difference
LL8A	Male	24	9.87	1.66	0.1	0.9	-1.2 to 1.4
	Female	14	9.78	2.39			
LL8B	Male	46	11.3	2.13	-0.3	0.5	-1.2 to 0.6
	Female	38	11.6	2.19			
LL8C	Male	70	13.3	1.94	-0.4	0.2	-1.1 to 0.3
	Female	87	13.7	2.21			
LL8D	Male	150	14.4	1.49	-0.3	0.1	-0.6 to 0.3
	Female	260	14.7	1.73			
LL8E	Male	219	15.4	1.09	-0.2	0.1	-0.4 to 0.3
	Female	264	15.6	1.38			
LL8F	Male	217	16.3	1.21	-0.2	0.1	-0.4 to 0.1
	Female	248	16.5	1.46			
LL8G	Male	116	17.6	1.52	-0.1	0.6	-0.5 to 0.3
	Female	149	17.7	1.61			

Table 4.10 Descriptive statistics for LL8 TDS by gender with results in years and p values of paired t-test.

4.4.13 Third permanent molars

The third permanent molar is considered the most variable of the permanent teeth, with the largest range in formation times. To investigate if development of the third permanent molar was longer than other teeth, all teeth with stages A-G available were compared. Stage G was chosen as the point at which tooth formation is almost complete instead of stage H, as there was no upper limit for this stage. The mean age of attainment from stages A to G was calculated for both genders. The second premolars and second permanent molars took approximately nine years to develop, whereas the third permanent molars took eight years to go from stage A to G.

The differences in hypodontia prevalence for the four third permanent molars indicated that right to left symmetry was variable for these teeth. To investigate this further, the right and left mean ages of attainment for the left upper and lower third permanent molars were compared (Table 4.11).

Gender	TDS	n-tds	Mean age of attainment in years (SD)		n-tds	TDS
Male	UL8A	4	8.8 (1.0)	9.6 (1.2)	8	UR8A
	UL8B	37	10.4 (1.7)	10.5 (2.0)	31	UR8B
	UL8C	54	12.3 (2.6)	12.4 (2.6)	58	UR8C
	UL8D	202	14.5 (1.6)	14.4 (1.7)	191	UR8D
	UL8E	219	15.3 (1.2)	15.4 (1.2)	212	UR8E
	UL8F	194	16.0 (1.1)	16.0 (1.1)	198	UR8F
	UL8G	130	17.3 (1.4)	17.3 (1.4)	130	UR8G
	LL8A	24	9.9 (1.7)	9.7 (1.6)	25	LR8A
	LL8B	46	11.3 (2.1)	11.2 (1.9)	45	LR8B
	LL8C	70	13.3 (1.9)	13.1 (2.0)	57	LR8C
	LL8D	150	14.4 (1.5)	14.4 (1.5)	154	LR8D
	LL8E	219	15.4 (1.1)	15.5 (1.2)	233	LR8E
	LL8F	217	16.3 (1.2)	16.3 (1.2)	218	LR8F
	LL8G	116	17.6 (1.5)	17.6 (1.4)	112	LR8G
Female	UL8A	9	9.3 (1.9)	9.3 (1.9)	8	UR8A
	UL8B	21	11.0 (2.6)	11.1 (2.2)	23	UR8B
	UL8C	56	12.9 (2.5)	13.0 (2.4)	59	UR8C
	UL8D	267	14.5 (1.7)	14.5 (1.7)	270	UR8D
	UL8E	273	15.3 (1.5)	15.3 (1.5)	260	UR8E
	UL8F	262	16.1 (1.3)	16.2 (1.2)	261	UR8F
	UL8G	158	17.5 (1.3)	17.4 (1.4)	161	UR8G
	LL8A	14	9.8 (2.4)	9.8 (2.3)	16	LR8A
	LL8B	38	11.6 (2.2)	11.7 (2.0)	36	LR8B
	LL8C	87	13.7 (2.2)	13.7 (2.1)	88	LR8C
	LL8D	260	14.7 (1.7)	14.7 (1.7)	256	LR8D
	LL8E	264	15.6 (1.4)	15.6 (1.4)	257	LR8E
	LL8F	248	16.5 (1.5)	16.3 (1.4)	247	LR8F
	LL8G	149	17.7 (1.6)	17.8 (1.6)	151	LR8G

Table 4.11 Comparison of n-tds, mean age of attainment and SD of right and left TDS for the four third permanent molars by gender

The mean ages for the right and left sides were almost identical and not significantly different. The upper and lower TDS on the same side was different for stages C ($p = 0.04$), E ($p = 0.02$), F ($p = 0.01$), G ($p < 0.001$) for females and stages B ($p = 0.04$), C ($p = 0.01$) and F ($p = 0.01$) for males. The mean age of attainment for males and females for stage F was approximately 16 years of age (SD 1.5 years), and for stage G, around 17.5 years (SD 1.5). Assuming that the data was normally distributed, this meant that if a male had a third permanent molar at stage F, 67% were likely to be under 18 years of age, (16 + 1.5 = 17.5 years). In reality some subjects in the DAA database with stage F were over 20 years of age, indicating that the data was not normally distributed.

For females the SD for the third permanent molars was greater for the early stages A–C (around 2 years), and was almost double the SD for the other permanent teeth. The same pattern was observed for males, although the SD for stages A-C was slightly smaller. This demonstrated the variation of third permanent molars, and the caution required when using these teeth to estimate age of young adults around the 18 year threshold.

4.5 Ethnicity distribution

The distribution of ethnicity of subjects contributing to the database is shown in Table 4.12. The majority of subjects were White, with Black being the second most represented ethnic group. Ethnicity was not recorded for 8% of subjects.

Ethnicity	**% (number)**
White	69.9 (1883)
Black	12.9 (340)
Mixed	5.1 (132)
Asian	2.8 (78)
Chinese	0.5 (13)
Other	0.8 (21)
Unknown	7.9 (209)

Table 4.12 Ethnicity distribution of TDS

4.5.1 Effect of ethnicity on age of attainment for TDSs

The TDSs were divided by ethnic group and gender (Appendices 13 & 14). Each table shows the number of subjects contributing to each TDS, and the mean age and SD of the age of attainment.

There were insufficient numbers per group for most teeth to compare ethnicity, as illustrated by the bar chart for the UL1 stage G in males, *n-tds* = 53 (Figure 4.28). ANOVA showed no significant difference between ethnic groups (p=0.5).

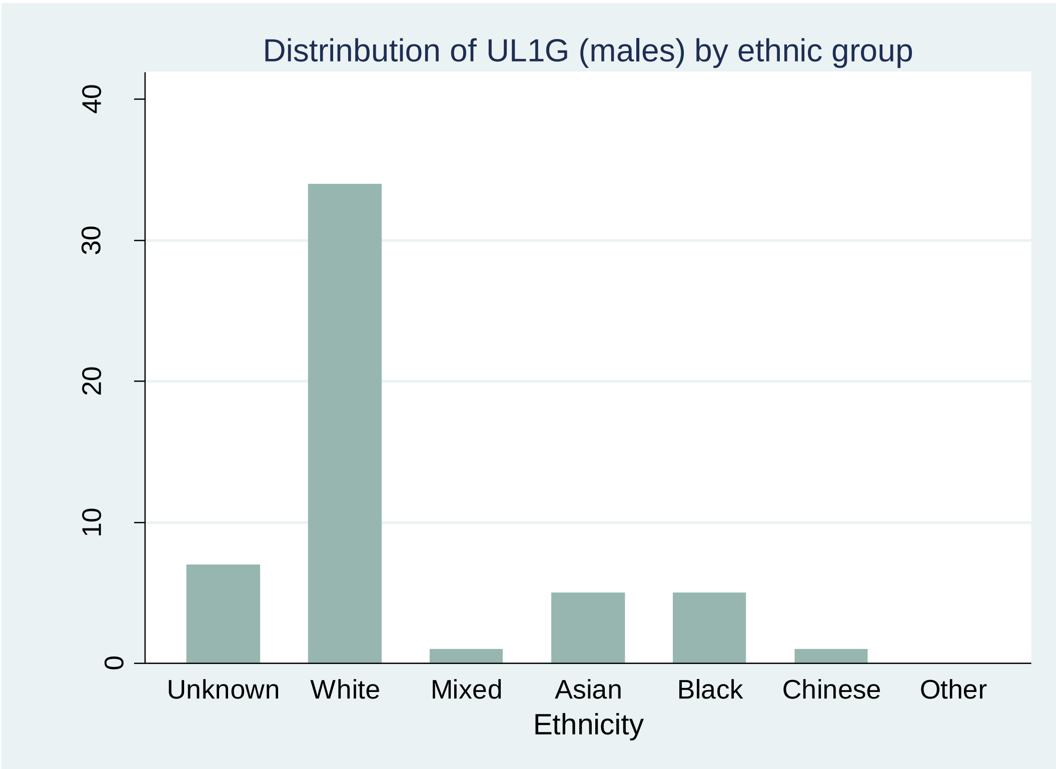


Figure 4.28 Bar chart for UL1G for males by ethnic group.

The DAA database was searched for teeth with an n-tds of > 10, for at least 2 ethnic groups per gender, such as the UL7G for males, in the White and Black groups (Figure 4.29). The only two ethnic groups with sufficient numbers were the White and Black groups, therefore when ANOVA was restricted to these groups, it directly compared White with Black. The results for the UL7G are shown in Table 4.13.

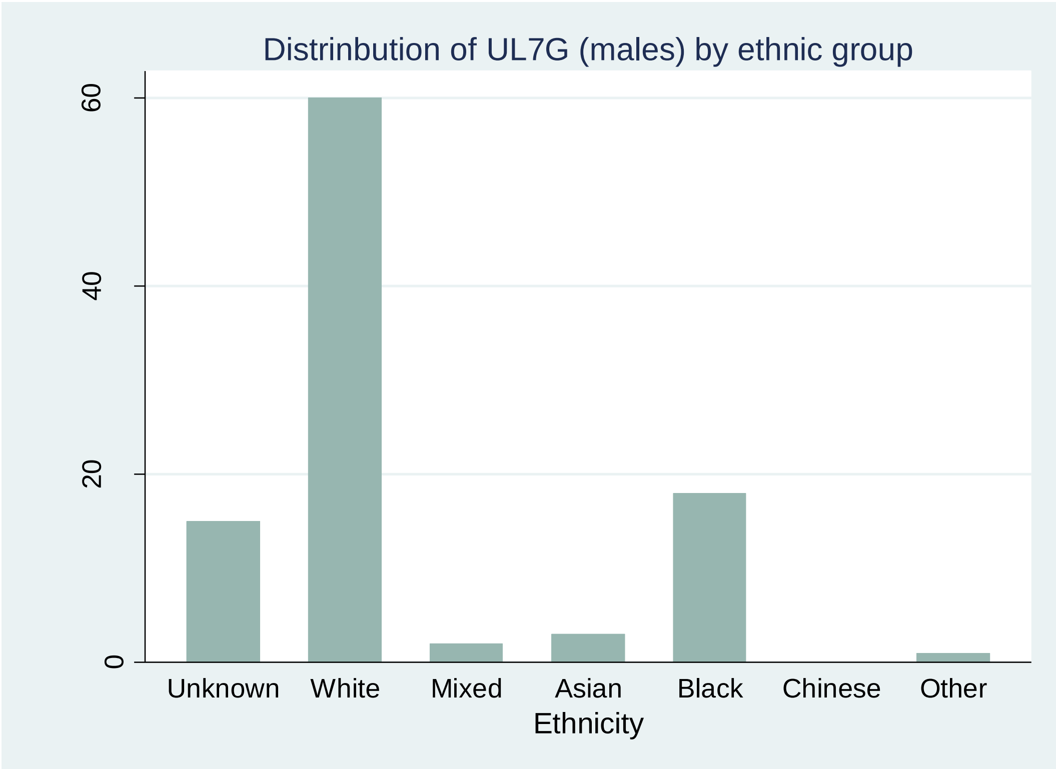


Figure 4.29 Bar chart for UL7G for males by ethnic group.

Ethnic group	n-tds	UL7G (males)	
		mean	SD
White	59	13.8	1.3
Mixed	1	16.9	N/A
Asian	3	12.6	1.7
Black	20	14.6	1.6
Chinese	0	0	N/A
Other	1	15.7	N/A
Unknown	15	14.7	2.1

Table 4.13 n-tds, mean and SD for the UL7G (males) by ethnic group.

The mean ages of the White and Black groups for the UL7G males were significantly different (p <0.00), according to Table 4.13, with Whites 0.7 years earlier than Black males. However with Bonferroni's correction there were no significant differences between males for the UL7G (e.g. for Whites vs. Blacks p = 0.05).

TDS	Gender	Ethnicity	n-tds	Mean age (years)	Difference (years)	95% CI of difference	ANOVA (p value)
UL7G	Male	White	59	13.9	-0.7	-1.4 to 0.1	0.05
		Black	20	14.6			
	Female	White	67	13.2	-1.7	-2.3 to -1.1	*<0.0001*
		Black	28	14.9			
UL8D	Male	White	139	14.3	-0.8	-1.4 to -0.2	*0.01*
		Black	31	15.1			
	female	White	189	14.4	-0.5	-1.0 to 0.1	0.05
		Black	53	14.9			
UL8E	Male	White	139	15.0	-0.7	-1.1 to -0.3	*0.001*
		Black	43	15.7			
	Female	White	204	15.1	-0.6	-1.1 to -0.1	*0.006*
		Black	43	15.7			
UL8F	Male	White	133	16.0	0.4	0.1 to 0.7	*0.03*
		Black	42	15.6			
	Female	White	192	16.2	0.4	0.4 to 0.8	*0.03*
		Black	55	15.8			
UL8G	Male	White	95	17.3	1.0	0.3 to 1.7	*0.004*
		Black	13	16.3			
	Female	White	124	17.6	1.3	0.8 to 1.8	*<0.0001*
		Black	27	16.3			
LL5G	Male	White	47	12.9	-1.5	-2.5 to -0.5	*0.007*
		Black	10	14.4			
	Female	White	63	12.8	-1.0	-1.5 to 0.5	0.06
		Black	12	13.8			

TDS	Gender	Ethnicity	n-tds	Mean age (years)	Difference (years)	95% CI of difference	ANOVA (p value)
LL7G	Male	White	98	13.9	-1.2	-1.7 to -0.7	*0.0006*
		Black	31	14.9			
	Female	White	115	13.8	1.8	0.6 to 3.0	*0.0001*
		Black	34	15.0			
LL8C	Male	White	48	13.7	0.8	0.6 to 2.2	*0.003*
		Black	10	11.9			
	Female	White	68	13.9	-0.5	-1.3 to 0.3	0.2
		Black	10	13.1			
LL8D	Male	White	118	14.3	-0.5	-1.2 to 0.2	0.2
		Black	16	14.8			
	Female	White	205	14.6	-0.4	-2.0 to 1.2	0.2
		Black	36	15.0			
LL8E	Male	White	141	15.3	-0.4	-0.7 to -0.1	*0.02*
		Black	45	15.7			
	Female	White	182	15.4	-0.3	-0.7 to 0.1	0.2
		Black	53	15.7			
LL8F	Male	White	130	16.5	0.8	0.5 to 1.1	*<0.0001*
		Black	53	15.7			
	Female	White	166	16.7	0.9	0.5 to 1.3	*<0.0001*
		Black	63	15.8			
LL8G	Male	White	76	17.8	1.5	0.7 to 2.3	*0.0006*
		Black	14	16.3			
	Female	White	105	18.1	1.7	1.1 to 2.2	*<0.0001*
		Black	36	16.4			

Table 4.14 Results of ANOVA by TDS and gender showing n-tds, mean and SD. Statistically significant results are shown in italics.

The only teeth which were not significant between White and Black groups, for either gender, were the UL8F and LL8D. The LL5G, LL8C and LL8E in females were also not statistically significant for the two ethnic groups. Of the remaining teeth, the majority showed Whites maturing later than Blacks, and were significant.

The exceptions were stages UL8F, UL8G, LL8C, LL8F and LL8G, where the reverse was seen, and again this was highly significant, as illustrated in Figure 4.30.

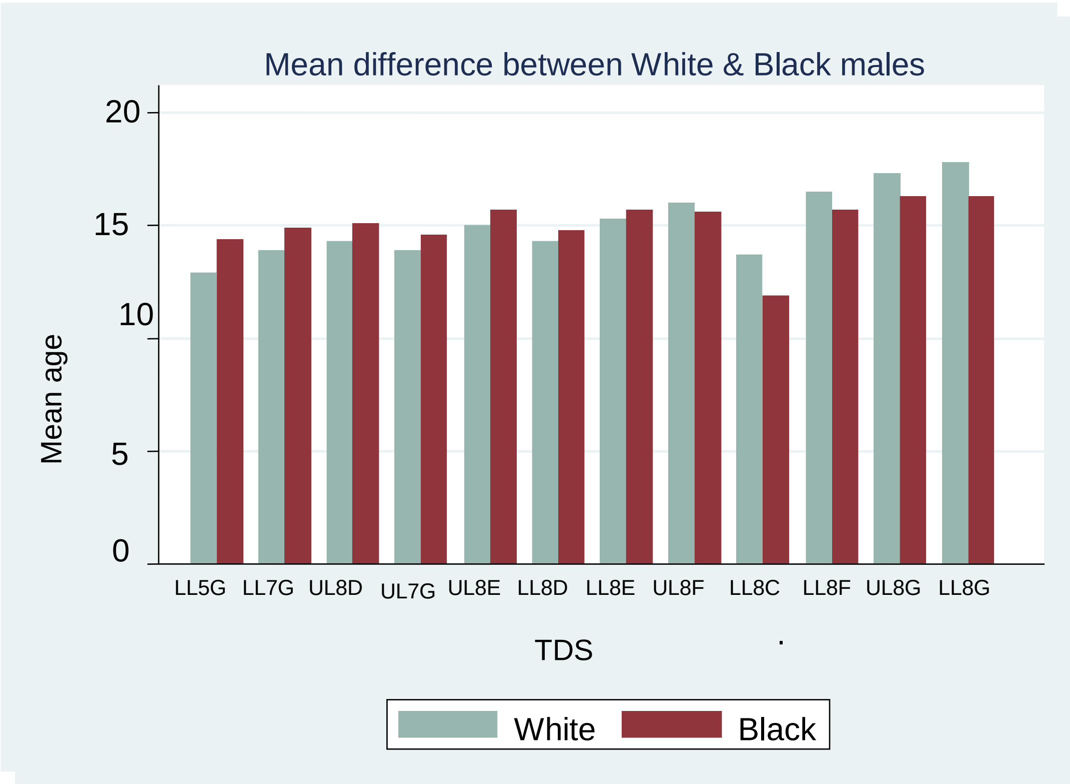
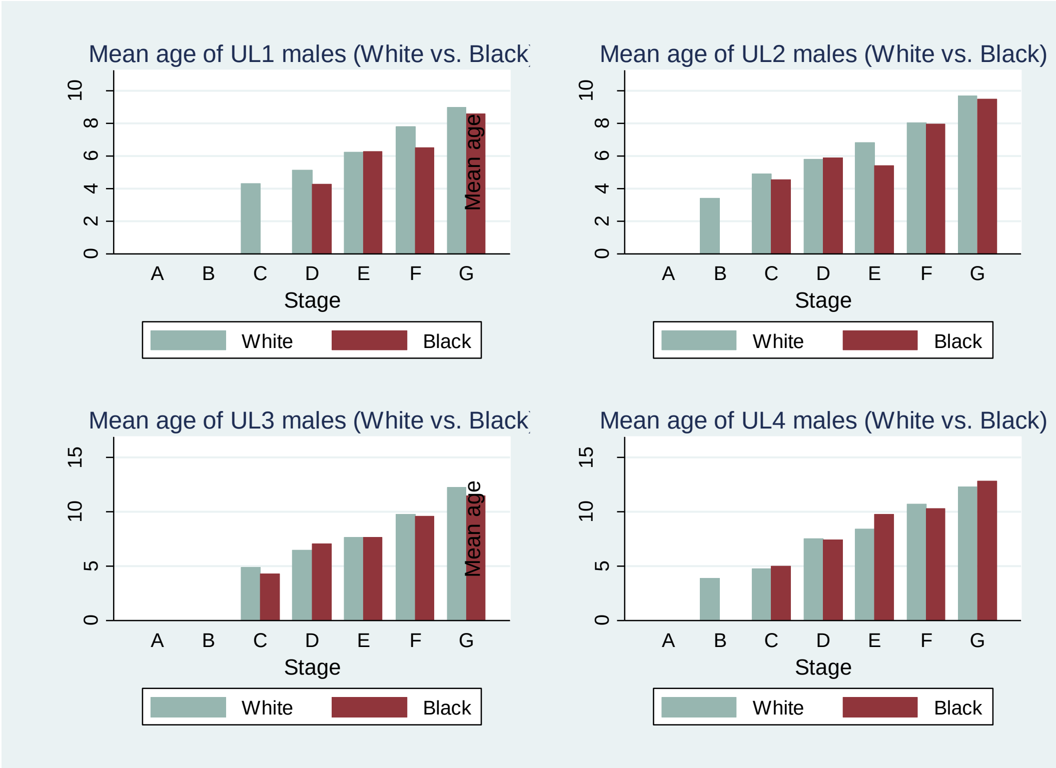
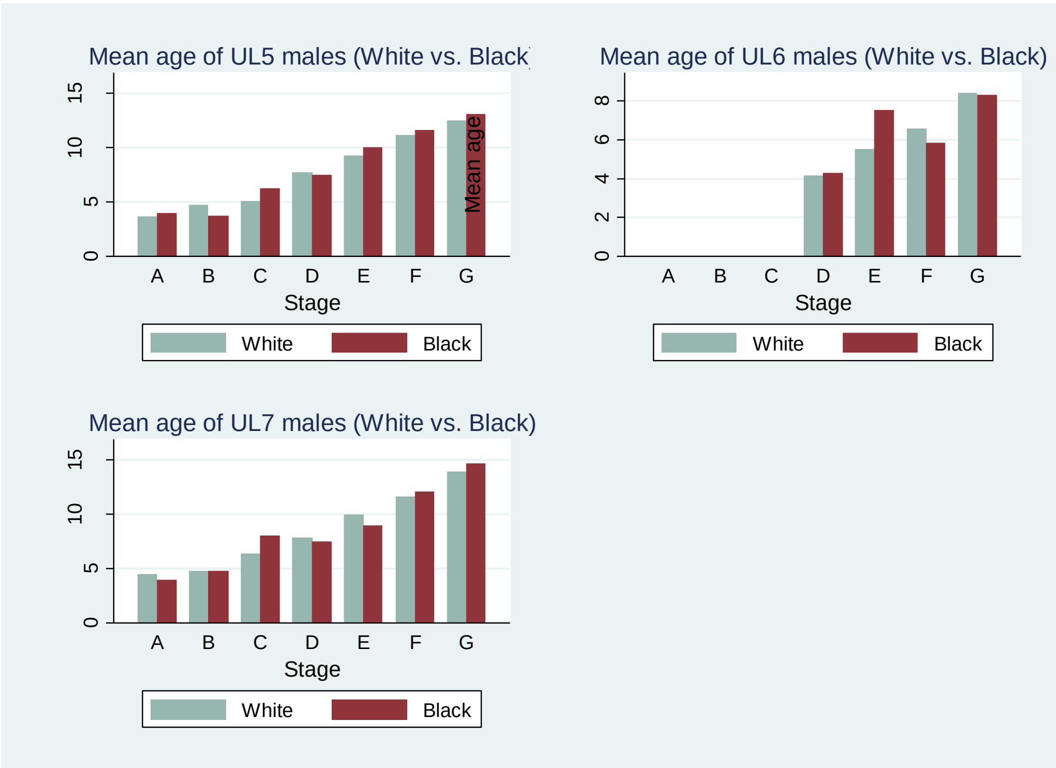
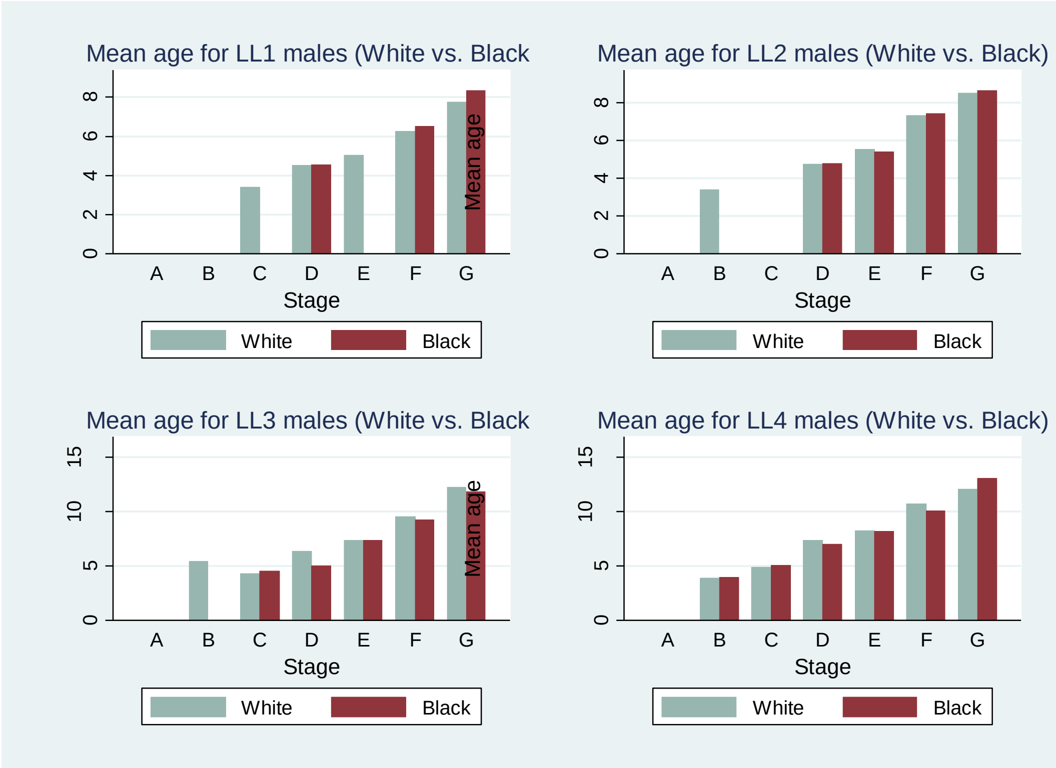


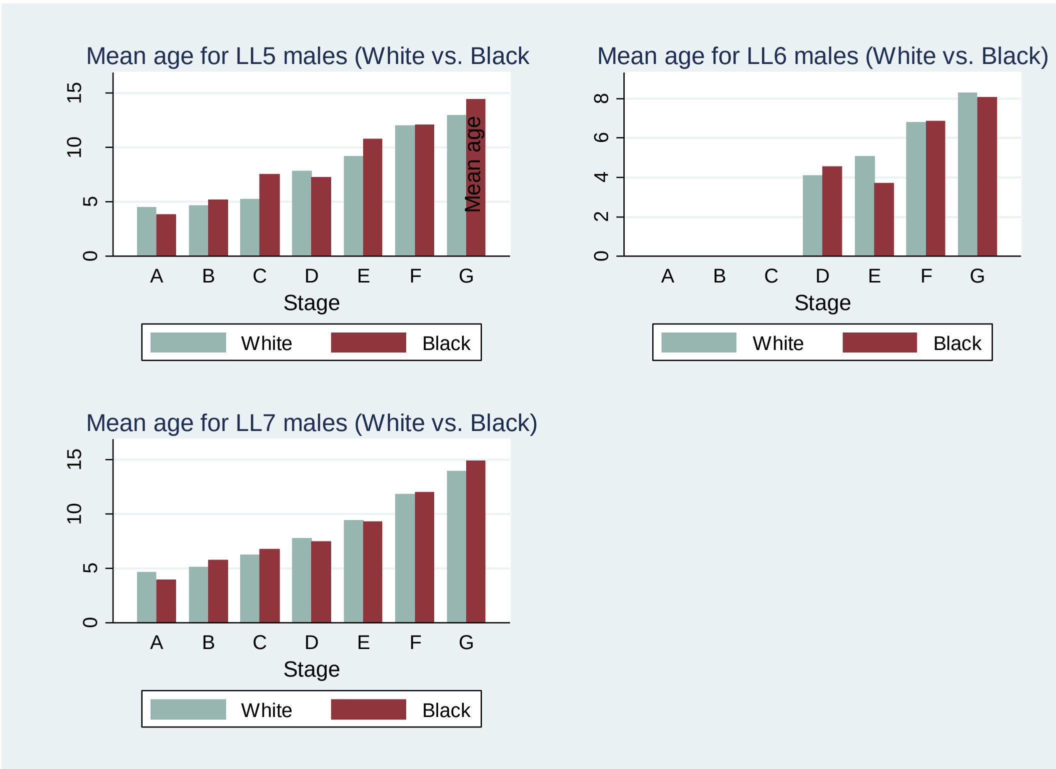
Figure 4.30 Bar chart of difference in mean age of attainment between White and Black males.

This suggests that in third permanent molars, Blacks matured faster than Whites, and that the opposite is true for the other permanent teeth. However, as only 3 TDS stages other than third permanent molars had sufficient numbers to compare, this conclusion needs to be viewed with caution. In fact, 70% of TDS in males, and 80% in females showed Blacks maturing earlier than Whites. This is demonstrated in Figure 4.31 for males. Whilst the numbers were small, there was clearly a difference between the two groups for all permanent teeth, not just the third permanent molars, with Blacks being younger than Whites. This averaged out as a difference of 2.5 months for all TDS, although the difference for the third permanent molars was over half a year (7.2 months).


Mean age of UL1 males (White vs. Black
Mean age of UL2 males (White vs. Black)
Mean age of UL3 males (White vs. Black
Mean age of UL4 males (White vs. Black)
Mean age
Stage
A B C D E F G
White
Black


Mean age of UL5 males (White vs. Black
Mean age of UL6 males (White vs. Black)
Mean age of UL7 males (White vs. Black)
Mean age
Stage
A B C D E F G
White
Black


Mean age for LL1 males (White vs. Black
Mean age for LL2 males (White vs. Black)
Mean age for LL3 males (White vs. Black
Mean age for LL4 males (White vs. Black)
Mean age
Stage
A B C D E F G
White
Black


Mean age for LL5 males (White vs. Black
Mean age for LL6 males (White vs. Black)
Mean age for LL7 males (White vs. Black)
Mean age
Stage
A B C D E F G
White
Black

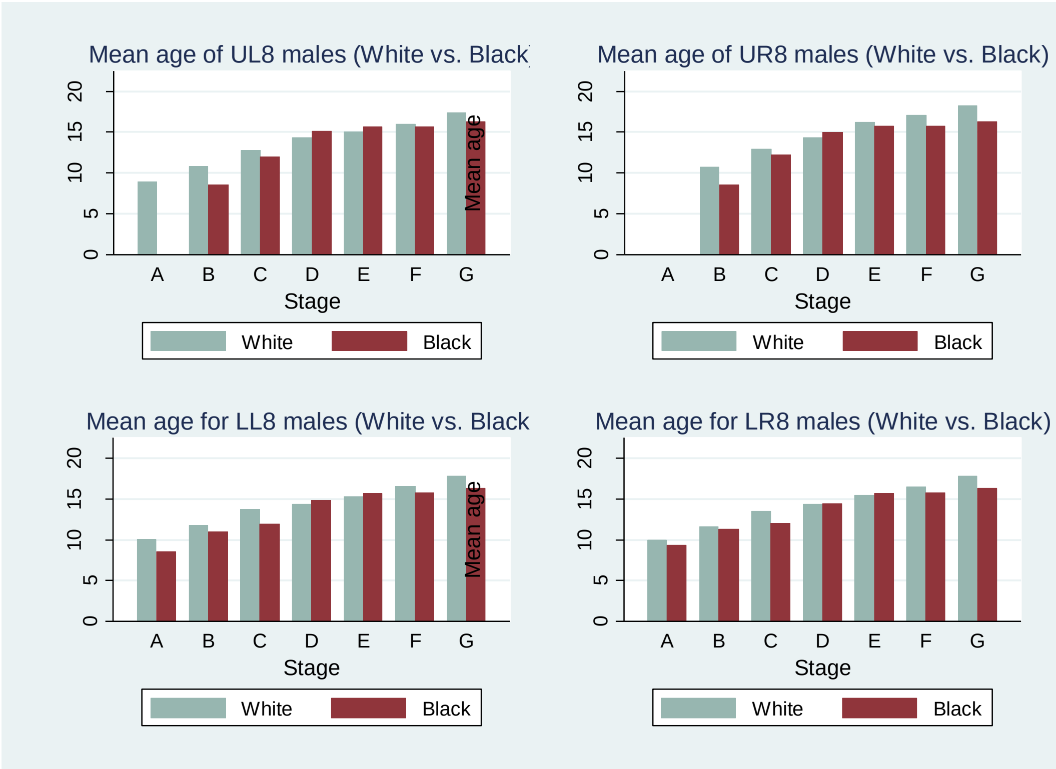


Figure 4.31 Bar chart of difference in mean age of attainment between White and Black males for all teeth.

4.5.2 Effect of ethnicity on estimated dental age

The mean and SD of the difference between DA and CA was analysed by ethnicity and gender, as shown in Table 4.15.

Gender	**Ethnicity**	**n-tds**	**mean of DA – CA (years)**	**SD of DA – CA (years)**	**95% CI (years)**
Males	White	722	-0.1	1.3	-0.2 to 0.0
	Mixed	31	-0.3	1.3	-0.8 to 0.2
	Asian	40	0.4	0.9	0.1 to 0.6
	Black	162	0.0	1.0	-0.1 to 0.2
	Chinese	7	-0.3	0.8	-0.1 to 1.0
	Other	9	-0.1	1.4	-0.9 to 0.5
	Unknown	120	-0.8	1.6	-1.1 to -0.5
Females					
	White	968	-0.2	1.4	-0.3 to -0.1
	Mixed	31	-0.2	1.1	-0.6 to 0.2
	Asian	46	0.0	1.5	-0.5 to 0.5
	Black	228	0.1	1.2	-0.1 to 0.2
	Chinese	5	0.2	0.7	-0.7 to 1.1
	Other	15	-0.5	1.1	-1.1 to 0.2
	Unknown	50	- 0.7	2.1	-1.3 to -0.1

Table 4.15 Mean, SD and 95% CI of difference DA – CA for ethnic groups using 8 stages.

The mean difference between DA and CA ranged from -0.8 to 0.0 years for males and -0.7 to 0.0 years for females, with the largest differences for the ethnicity unknown group. The SD of the difference between DA and CA varied from 0.8 to 1.6 and 0.7 to 1.5 years for males and females respectively. Positive mean values were noted for Asian and Black male subjects, with DA over-estimating age. DA was greater than CA for females from the Asian, Black and Chinese groups, although the Chinese group was very small. (The 95% CI for Whites and Blacks for both genders were narrow, 0.2 and 0.3 years respectively due to the large n-tds).

Due to the small numbers of subjects in some groups, useful comparisons could again only be made between Whites and Blacks. DA in the Black group, for both genders, was slightly larger than CA, resulting in an over-estimation of age. This implied that children and young adults of Black ethnicity were maturing faster than their counterparts of White ethnicity. This reinforced the finding when comparing the mean ages of attainment between the two groups, which showed that for the majority of TDS, Blacks matured earlier than Whites.

4.6 Discussion

This chapter compared the accuracy and precision of two staging systems using the weighted average method. There was no difference in DA estimation between 8 and 12 stages for either gender or age group, and the reproducibility of 8 stages was better, indicating that 8 stage system was preferable. The effect of ethnicity on tooth development could only be investigated between White and Blacks. This demonstrated that Blacks matured earlier than Whites for most TDS.

4.6.1 DAA database

One of the main difficulties encountered was obtaining sufficient DPT's for the study, even though pressure sensitive duplicating consent forms were introduced. This restricted the number of radiographs that were available for assessment, and meant that numbers for each ethnic group were small. Although there were 2426 subjects in the DAA database, which was comparable to when the 2928 subjects in Demirjian’s 1973 study, when the groups were further subdivided by gender and ethnic group for each TDS it became clear that numbers for most teeth were small. This research was not amenable to sample size calculations, and the only advice available regarding sample numbers for reference standards is provided by the WHO, which advised 100 subjects per gender, ethnic group and TDS. That would require 21,600 subjects, which was clearly not feasible for this study. In addition, it was noted when analysing the data, that certain ethnic groups and TDS were not well represented, such as early stages of the early and intermediate developing teeth, and subjects of Asian, Chinese and Other origin.

One way to increase subject numbers was to include assessments from several investigators. Whilst this improved numbers, when the DAA database was analysed for data checking, it was noted that three investigators had not recorded both systems for each DPT. This reduced the number of subjects for whom DA using 12 and 8 stages could be estimated and compared. The primary investigator went through all records, both paper and electronic and amended assessments where possible;

however the number of subjects that could be compared was reduced from 2621 to 2426 (92%).

This was also a problem when determining the status of teeth present or missing in the sample, as investigators had not recorded this routinely. Despite rechecking all entries, data were only available for 2009 subjects (76%). Of the remaining images, only 2% were excluded due to poor image, indicating that the use of DPT's for the weighted average method was appropriate. The prevalence of hypodontia was highest for the third permanent molars, ranging from 10-13%. This compares to the range of 10 -15% in a previous UK study (Gravely 1965) but less than the 37% observed in a Spanish population (Bolaños et al. 2003). However the latter study included children aged 4 to 20 years, and did not distinguish between third permanent molars missing due to hypodontia and development, which may explain the larger prevalence. The low proportion of hypodontia in third permanent molars justifies their inclusion for DA estimation.

This highlighted the importance of distinguishing between teeth missing due to hypodontia or development, in third permanent molars. The earliest visualisation of this tooth in the DAA database using the 12 stages as described by Haavikko (stage ‘o’ for crypt formation) was 6.39 years for females and 6.55 years for males. Using the 8 stages described by Demirjian, with stage A corresponding to cusp calcification, the youngest age for the third permanent molar was 6.78 years for females and 7.05 years for males. This compares with the earliest radiographic appearance of the third permanent molar of approximately 7 years of age (Gravely 1965). However this is earlier than the age for cusp calcification observed by authors at around 9 years of age (Garn et al. 1962; Levesque et al. 1981), and older than 5.83 years noted in another study (Bolaños et al. 2003). Comparison between studies is difficult as different staging methods were used, but it seems that most third permanent molars start to develop around 8-10 years of age. The latest stage A third permanent molar in the DAA database was 14.2 years for males and 13.7 years for females, meaning that if the third permanent molar has not appeared by 14 years of age, it is almost certainly missing due to hypodontia, which is supported by the literature (Garn et al. 1962; Baba-Kawano et al. 2002).

The gender distribution in the DAA database was 55% female and 45% male, which was identical to a study by Nortjé (Nortjé 1983). In Demirjian's study, the gender balance was almost equal (49% males) and in Haavikko, there were slightly more males than females (52%).

4.6.2 Weighted average method

The accuracy of the weighted average method when tested using the DAA subjects and both 12 and 8 stages showed that there was no difference in outcome between the two staging systems. The mean difference between CA and DA was 2 months (0.14 years) for both genders. This is smaller than a previous study where the mean differences were 0.7 years for males and 0.6 years for females (Eid et al. 2002). DA over estimated age, a finding consistent with previous studies using Demirjian's stages (Koshy & Tandon 1998; Eid et al. 2002; Liversidge et al. 1999).

The SD was approximately 1.3 years for both staging systems and both genders.

The 95% CI range for both genders and staging systems was narrowest at 0.3 years. However, it must be remembered that the 95% CI interval was related to the mean difference of the sample population and not the individual variation. The weighted average is proportional to the sample size, but inversely proportional to the square of the SD (section 3.1.6.4); therefore the influence of SD is far greater than n-tds. This means that even though the sample size was large, the individual variation within subjects carried more weight. Therefore whilst the weighted average method shows good precision, the validity of the method is less clear.

Several authors have suggested that DA estimation is more accurate in children less than 10 years of age, and for this reason the database was split at 10 years. The mean DA was greater than CA for <10 years and less for >10 years. The reason why there should be a shift from overestimation to underestimation at 10 years is not obvious. To investigate if the number of developing teeth influenced the accuracy of DA estimation, age was further divided into yearly intervals. The results showed that the degree of over to under estimation was not related to the number of subjects in each age group or SD. The only negative values for DA-CA were observed at 8-9 years and 15-16 years in males and 9 and 15-16 years in females, with all other age groups being positive. This was observed for both staging systems. The change from over to under estimation at 9 years coincides with the maximum number of developing teeth available for assessment (Figure 4.5) and may explain the observation.

The second switch from over to under estimation at around 15 years is harder to explain, as it is not related to the number of developing teeth. It does coincide with the onset of puberty (which also corresponds to the largest variation in SD for TDS as shown in Figures 4.16 & 4.17), and may indicate that tooth development is related to hormonal changes in the body, although studies have shown that hormonal imbalance does not appear to effect tooth development or sexual dimorphism (Garn et al. 1965a; Guatelli-Steinberg et al. 2008). Another explanation may be due to the sample used; the majority of younger children were diagnosed with caries, and came from more socially disadvantaged backgrounds, whereas the adolescents were mainly orthodontic patients, generally caries free and from less deprived backgrounds. The differences in age groups may be related to socioeconomic status and nutrition, although this is less likely as DA has been showed to be less affected by nutrition (Lewis and Garn 1960; Tonge & McCance 1975; Green 1961; Melsen et al. 1986). It is likely that the increasing difference between DA & CA with age, is due to the fact that the relationship between CA and DA is strongest during the phase of rapid growth and development in the young, and weakens when growth has slowed substantially in the adult (Black & Maat 2010).

The differences observed may also be the result of small samples diminishing the power of statistical analysis. However it does indicate that a degree of caution is needed when analysing data, as the assumption of underestimation of DA for less than 10 years would have remained if further age groups had not been investigated.

The Bland - Altman plots not only demonstrated the degree of over and under estimation of the two age groups, but also the increasing scatter with advancing age.

This appeared to be due to the diminishing number of teeth available for assessment as an individual matures and therefore the increasing variability. The 95% limits of agreement were also wider for the older age group as was the SD, indicating that the SD of mean age of attainment of TDS increased in later stages and with increasing age.

The Bland – Altman plots of DA8 and DA12 also showed that scatter increased with age, indicating that the discrepancy between the two staging systems increased with CA. This meant that with fewer teeth to assess, the variation of each TDS for both staging systems increased with the resulting inconsistency between 8 and 12 stages.

It was important to test the weighted average method on an independent sample, as it could be argued that using the subjects in the DAA database would introduce bias. Even though the impact of each individual subject when compared to the total number in the database was likely to be minimal, this could be considered a criticism of the method. As the difference between using 8 or 12 stages had already been shown to be negligible, and 8 stages demonstrated better reproducibility, the 8 stages were used to determine DA for the study group. For both genders the mean difference between DA and CA was positive, showing DA was overestimating age for the 200 subjects in the study group. In addition, the mean difference was larger for the study group than for the DAA database, which was to be expected as the subjects in the DAA database were a self-referential sample, whereas the independent sample were randomly selected.

Displaying the distribution as histograms gave the impression that the larger the n-tds, the more closely the data resembled normality. However, when the Shapiro-Wilk tests were performed, it was seen that the n-tds had little effect, as even the third permanent molars which had larger n-tds numbers for all stages were not normally distributed across all stages. This reinforced the importance of SD and outliers, as most stages were skewed to the right due to outliers in the older age groups.

4.6.3 Gender

The permanent teeth, except the third permanent molars, developed earlier for females compared to males. For the third permanent molars, the reverse was seen, with males maturing faster than females. This agreed with other studies (Garn et al 1962, Willerhausen et al 2001, De Salvia et al 2005, Nyström et al 2007), but disagreed with studies that found that females matured earlier than males for stages A-D (Levesque et al 1981) or for stage G (Olze et al 2004).

4.6.4 Stage H

The cumulative frequencies graph for the UL1H (Figure 4.1) highlighted the problem with stage H and the need for censoring of the data to find the upper limit and median value. This was a particular issue when the third permanent molar has fully matured. In this study, the median age of attainment for stage H of the upper third permanent molar, after censoring, was 19.1 (UL8) and 18.9 (UR8) years respectively in males. This is earlier than median ages stated by others; 20.02 years (Mincer et al 1993) and 22.8 years (Olze et al 2004). However, these two studies involved subjects with an upper age limit of 24.9 years for the Mincer study and 30.0 years for the Olze study, with uncensored data. This is also demonstrated by a study with an upper age limit of 20 years, with a median age of 18.62 and 18.8 years for the upper third permanent molars (Bolaños 2003).

The same pattern was noted for the lower third permanent molars in males and females. Similar values were noted for the median ages of attainment for both genders, comparable to other authors (Mincer et al 1993, Olze et al 2004, Prieto et al 2005). The use of stage H for DA estimation is restricted to stating the age at which 50% of the population would be expected to have reached maturity.

4.6.5 Interval between stages

It was not possible to determine the timing of tooth initiation for the early developing teeth, as these teeth start to mineralise within the first two years of life, and were therefore outside the age range for this study. The only teeth for which all stages A-

H were visible were the second premolar, second molar and the third molars. Crown initiation for the second molar was 3.7 years for females and 4.3 years for males. This is slightly older than the 3 years of age noted in a previous study. This study was based on histological samples which are deemed more accurate than radiographic assessment (Reid and Dean 2006, Nyström et al 2007), which may explain the younger age at initiation.

The differences in time interval between early, intermediate and late developing teeth noted in this study have not been described in the literature. Most authors have noted larger time intervals for the later stages (Moorrees et al 1963, Demirjain and Levesque 1980, Nykänen et al 1998). The study by Demirjian and Levesque showed longer time intervals for the seven mandibular teeth compared to the present study, with a more linear pattern of growth and the longest time interval for stages E-F. Third permanent molars were not included in their study, therefore the trend for later developing teeth demonstrating longer time intervals for the early stages could not be compared.

The differences in time interval between stages demonstrated in figures 4.23 & 4.24 may be due to the fact that the 8 stages used to describe the developing tooth are based on discernible tooth formation changes rather than dividing tooth formation by equal time intervals. This means the time taken for a tooth to develop from one stage to the next is not identical, nor is it related to the anatomical morphology (Figure 2.3). This is illustrated by the Atlas of tooth development and eruption developed at The Barts and The London Institute of Dentistry (AlQahtani 2008), which shows very little change in the morphology of the UR1 from 2.5 years to 3.5 years (Figure 4.32), but noticeable differences, from 6.5 to 7.5 years (Figure 4.33).

Figure 4.32 Atlas of tooth development and eruption (AlQahtani 2008).

Figure 4.33 Atlas of tooth development and eruption (AlQahtani 2008).

In addition, the time taken for the cusps of a permanent molar tooth to form and coalesce is not the same as the time required for the incisal edge of an incisor, although both are considered as stage A. Therefore it follows that the time taken from stage A to B would not be equal for all teeth. Another reason for the data distribution seen in Figures 4.23 & 4.24, is the small numbers of n-tds for the early stages of the UL5 and later stages for the LL8, making statistical analysis less robust for these stages.

4.6.6 Third permanent molars

The upper third permanent molar developed earlier than the lower, which agreed with the results of a previous study (Haavikko 1970), although no difference was noted between right and left sides, which was similar to study of German subjects by Olze (Olze et al 2003). This meant that it was not necessary to record both right and left third permanent molars if they were the same stage (as the mean age was the same) but if both upper and lower third permanent molars were present on one side, both needed to be assessed as the mean age of attainment differed.

Males matured earlier than females, which was supported by the literature, as shown in Table 4.16, comparing the mean age of attainment for Whites from the present study and three other studies investigating the third permanent molar who reported the mean ages using Demirjian's 8 stages, and all used Caucasian subjects (Thorson and Hägg 1991; Olze et al 2003; De Salvia et al 2004). The mean ages described in the paper by Thorson and Hägg are credited to Levesque et al 1981, although the Levesque paper gave median ages and it is not clear how these were converted into mean ages.

Study	**Tooth**	**Gender**	**Stage (mean age in years)**				
			C	**D**	**E**	**F**	**G**
Present	18	Male	13.1	14.7	16.1	17.2	17.8
		Female	13.4	14.4	15.1	16.2	17.7
Olze		Male	13.6	16.5	16.7	17.8	20.6
		Female	14.2	15.7	16.8	18.6	20.7

Present	38	Male	13.7	14.3	15.3	16.5	17.8
		Female	13.9	14.6	15.5	16.7	18.1
Olze		Male	14.6	16.3	16.7	18.3	21.3
		Female	14.5	15.5	16.8	19.1	21.7
Thorson & Hägg		Male	12.7	13.9	15.4	16.9	18.4
		Female	12.4	13.7	15.4	17.3	19.5
De Salvia		Male		17.1	17.3	18.9	20.7
		Female		17.2	16.1	19.2	20.7

Table 4.16 Comparison of mean age of attainment for upper and lower third left permanent molar using 8 stages.

The mean ages of attainment for the present study were lower than for the other studies (except Thorson and Hägg), which may be a reflection of the age group sampled (7 – 25 years for the Levesque study, 14.5 – 25 years for De Salvia and 12 – 26 years for Olze, versus 2 -25 years for the present study). Stage H was not included.

The fact that the duration of mean age of attainments for the development of the third permanent molar from stages A – G was shorter than the second premolar and second permanent molar, would suggest that the third permanent molar should be less variable then other permanent teeth. In reality, the range of values for mean age for the third permanent molar was up to 14 years for individual TDS, as opposed to an average range of 6 years for other teeth. This meant that even though the third permanent molar matured at a regular rate, the wide range of values in its initial development produced the variation noted. The shorter time for duration of development is likely to be caused by the fact that the third permanent molar has the shortest root length of the permanent molar teeth (11.0mm compared to 14.0mm for the first permanent molar), and therefore it would be expected that it would take less time to form (Osborn 1981).

4.6.7 Ethnicity

A shortcoming of this study was the small sample size for most ethnic groups, making comparison of only Whites and Blacks possible, with this being mainly restricted to the third permanent molars. The effect of ethnicity on the development of the third permanent molar has been demonstrated previously, with Blacks maturing earlier than Whites (Olze et al 2004, Blankenship et al 2007, Liversidge 2008). The study by Olze found that Blacks developed faster than Germans and Japanese for stages D-G, and Blankenship demonstrated Blacks maturing faster than Whites for stages D-F. The trend was reversed for stage G with White males maturing earlier than Black males. In this study, Whites matured faster than Blacks for stages A-E, and the reverse was seen for stages F-G for both sexes and upper and lower teeth.

It was expected that Blacks would mature earlier than Whites for all teeth and all stages, with Black children and young adults having a younger mean age of attainment for the majority of TDS. Unfortunately due to the small number of Black subjects for most TDS, it was not possible to analyse them formally.

The problems of accurately estimating age for young adults using the developing dentition led to the use of alternative methods for age assessment, which will be explored in the next chapter.

5. Comparison of sternoclavicular joint and root canal width

The problem of age estimation for young adults with no permanent teeth still developing has already been highlighted (section 2.9). To address this, the use of the sternoclavicular joint (SCJ) and measurement of root canal width (RCW) of the teeth were assessed to determine their usefulness for age estimation (section 2.10). Therefore the aim of this chapter was to obtain the mean ages of attainment for the different stages of SCJ and RCW and assess the reproducibility of these methods. In addition, the combination of DA, SCJ and RCW was investigated to determine if this improved the accuracy of age estimation.

5.1 Methods

5.1.1 Assessment of the Sternoclavicular Joint

Ethical approval for the retrospective assessment of the ossification of the SCJ was received from the Kings College London Hospital Trust Joint Research and Ethics Committee (project number: 07/H80808/122). The SCJ was assessed according to the five stages described in section 2.10.2 (Schmeling et al 2004).

5.1.1.1 Inclusion criteria for chest radiographs

- Children and young adults aged from 12-32 years for whom chest radiographs were available. The age range of 12-32 years was chosen as most studies showed the youngest age for stage 1 to be 12 years, and the oldest age for stage 5 was 31 years (Schmeling et al 2004; Schulz et al 2008b).
- Images of sufficient quality to allow assessment of the ossification of the SCJ.

5.1.1.2 Chest radiographs

The radiology department at KCH provided a list of all patients for whom chest x-rays and computerised tomography (CT) scans were available from 2006-2009. For training purposes, conventional chest x-rays and CT scans were viewed on a dedicated viewing screen, in a darkened room, in the department of Radiology. Due to limitations in availability of these dedicated viewers, it was decided that the images would be assessed on a 21 inch monitor screen, in the dental department, via the KCH intranet, using the PAX computerised system. The images were viewed in a darkened room with low ambient light, to aid assessment.

Initially chest x-rays and chest CT scans were randomly selected, and the ossification of the SCJ assessed, by the PI and a radiologist for training purposes. Visualisation of the SCJ using CT was extremely difficult and varied according to the positioning of the patient, machine used and slice thickness of the scan. During the training session it was decided to concentrate the assessment of SCJ on digital x-rays only, as these gave better visualisation. Therefore the PI contacted the Radiology department at KCH and requested the hospital numbers of patients with digital radiographs within the age range specified. The SCJ on both the right and left sides were assessed. If either SCJ was not visible, this was also recorded.

An Access table was created in the DAA database to input SCJ data and obtain mean ages of attainment for the five grades for both right and left sides. Differences between genders were investigated, but information regarding ethnicity was not available. The tables were imported into Excel (in a similar manner to the ages of attainment for the TDSs) and the number, mean age of attainment, SD, SE and 95% confidence intervals (of the mean) for the five grades of SCJ were derived for each gender. Stage 5 had to be viewed with caution, as there is no upper limit for this stage (in the same way that stage Ac/H has no upper limit). Therefore the mean age of attainment for stage 5 was dependent on the upper age limit in the sample.

5.1.1.3 Reproducibility of SCJ

Intra-examiner reproducibility was investigated by the primary investigator re-assessing 50 chest x-rays after a two month period. Inter-examiner agreement was measured by the primary investigator and a consultant radiologist both assessing 20 chest x-rays, with Cohens's Kappa used to measure reproducibility.

5.1.2 Assessment of the Root Canal Width

Ethical approval for assessing DPT's had already been obtained (section 3.2.1), therefore the RCW method could commence straightaway.

A method was required to reliably and consistently measure the width of the distal root canal of the lower permanent molars from a digital image. The problem was to measure the canal width at the same point in all teeth, as it was not sufficient to just measure the widest part of the canal. Depending on how the line connecting the two points was angled, it could make the canal appear wider than it actually was, as shown with the white lines in Figure 5.1.

Figure 5.1 Measurement of the distal root canal using different angulations.

To combat the problems of angulation it was decided to draw a line across the floor of the pulp chamber and measure the root canal width perpendicular to this line (Figure 5.2).

Figure 5.2 Measurement of the distal root canal using a line drawn perpendicular to the floor of the pulp chamber.

Several software packages were trialled for suitability:

- Adobe Photoshop™ version 8.0 (Adobe® California, USA).
- UTHSCSA Image Tool for Windows™ (version 3.00, University of Texas Health Science Center, USA).
- ShapeFind 2D.

None of the above was suitable, as it was either not possible to construct the lines required, or the reproducibility of the measurements was extremely poor; therefore a categorical method of grading the RCW of the lower left permanent molars was devised

5.1.2.1 The RCW method

The digital images of the DPT's were acquired using the methodology previously described (section 3.1.5.1).

This method was devised by the PI and second supervisor in 2008, and used to assess all DPT's from that point onwards. As the pulp cavity becomes smaller with age, earlier developing teeth have more secondary dentine deposition, and hence smaller pulps, than teeth developing later. For this reason the 3 permanent mandibular molar teeth on the left quadrant (LLQ) were chosen, as they represent early, intermediate and late developing permanent teeth that can be easily visualised on a DPT. The distal root was chosen as it completes development later than the mesial root in permanent molars (Liversidge 2008a). For example, the distal root of the lower left second permanent molar was denoted as LL7d. Figure 5.3 illustrates the grading system. The advantage of this method was that it did not require specialised software and could easily be used to gain the information about an individual from a DPT.

The widest part of the distal root canal was assessed for each tooth, and compared to the adjacent molar tooth to determine which canal was wider, or whether they were of equal size. Therefore grade 1 indicated that the distal canal of LL8 (LL8d) was wider than LL7d, which in turn was wider than LL6d, as shown in Figure 5.3. Grade 2 was designated when the LL8d was wider than the other two teeth, but the LL7d and LL6d were of equal width. Grade 3 indicated that the distal canals in the three teeth were the same size. Grade 4 and 5 were similar to grades 1 & 3 respectively, but were assigned to cases when the third permanent molar was absent. This information was required, as the age range for subjects with missing third permanent molars may have been younger than for subjects with third permanent molars.

If the teeth had not reached the development stage to assess the root canal, a score of not applicable was recorded. The grade was recorded in the DAA database, using a table devised to record the RCW method. For each of the five grades, the mean ages of attainment were obtained for males and females separately.

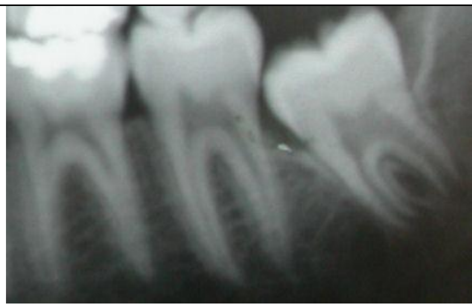
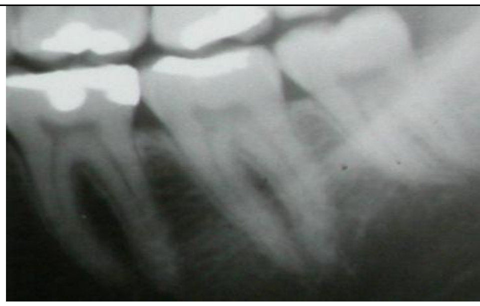
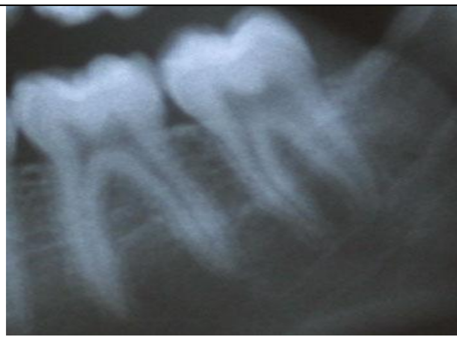
RCW grade	RCW description	Image
1	LL6d<LL7d<LL8d	
2	LL6d=LL7d<LL8d	
3	LL6d=LL7d=LL8d	
4	LL6d<LL7d (LL8d missing)	
5	LL6d=LL7d (LL8d missing)	

Figure 5.3 Grading system for assessing RCW

5.1.2.2 Reproducibility of RCW

To test for intra-examiner reproducibility of the RCW method, 50 DPT's were re-assessed by the PI after a two month period. Inter-examiner agreement was investigated by the PI and another investigator both assessing 20 DPT's, after a two week period.

5.1.3 Comparison of DA, RCW and SCJ

To compare the three methods, individuals with both DPT and chest x-rays were required. The Maxillo-facial department at KCH was contacted to identify potential subjects, within the study age range. Following discussions with the Consultant in Maxillo-facial surgery, it soon became apparent that there was no process in the department to identify the subjects required. The radiology department at KCH was then contacted, and a list of all patients from the main hospital, with chest x-rays and DPT's taken in the period 2008-2009 were cross referenced, and potential subjects with both x-rays taken on the same day isolated. Of the 536 subjects on the list, only 25 (4%) had both a DPT' and chest x-ray taken on the same day. This was clearly a small number of subjects, and limited statistical analysis.

For each of the 25 subjects, the teeth on the left side were assessed and the corresponding DA calculated, along with the mean age of attainment using the RCW and SCJ. To ascertain if the combination of DA, RCW and SCJ improved the accuracy of age estimation, the weighted averages for DA, SCJ and RCW were calculated using the formula previously described in section 3.1.6.4:

$$\text{Weighted average} = \frac{\sum (1 / se_i^2) \times m_i}{\sum 1 / se_i^2}$$

The weighted average for the individual was called the Estimated Age (EA).

5.1.4 Statistical considerations

Cohen's kappa was used to measure the intra and inter-examiner reproducibility of SCJ and RCW. Paired t tests were performed to determine any differences between left and right sides for SCJ and between genders for SCJ and RCW. Bland and Altman plots were used to measure the agreement between EA and CA for the combination of DA, SCJ and RCW.

5.2 Results

5.2.1 SCJ

Eight hundred and thirty two x-rays were available, of which 463 (55%) could not be assessed, due to poor image or superimposition of other structures. For the remaining 369 subjects (169 male and 200 female, age range; 8.3 – 36.3 years), the age distribution of subjects is displayed in five-yearly intervals (Figure 5.4). The 30-35 year group was most common for both males (n=55) and females (n=72), followed by 25-30 years.

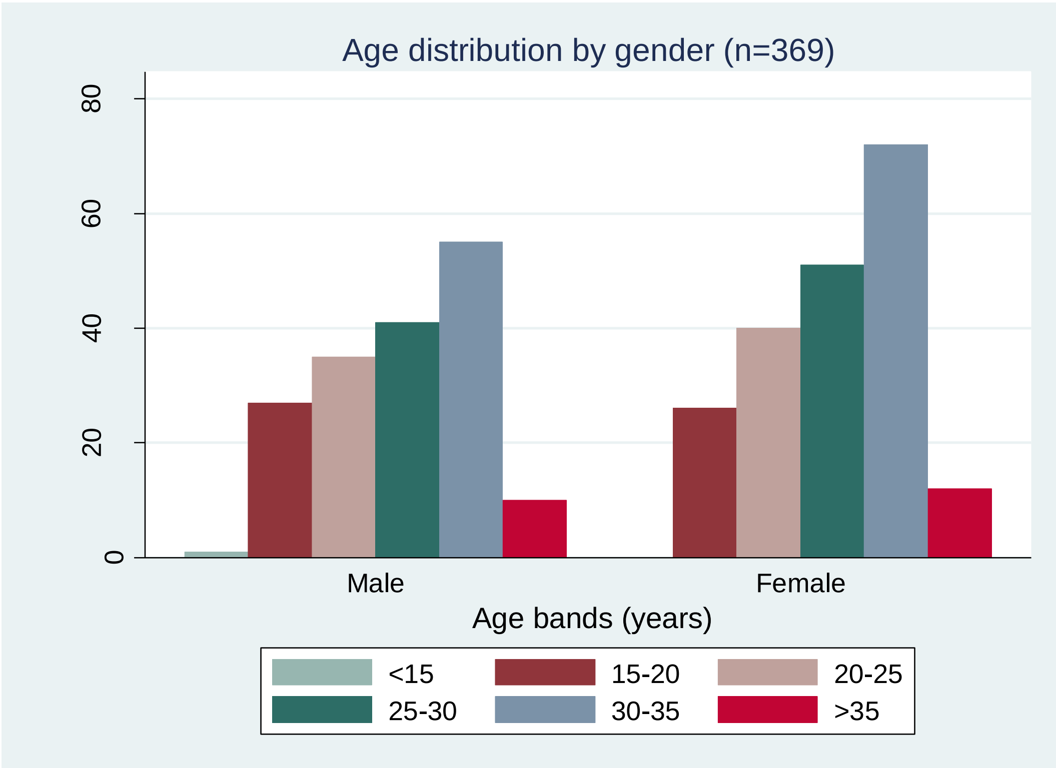


Figure 5.4 Age distribution of the subjects assessed for SCJ study

The SCJ was not always discernible, resulting in the assessment of 570 out of a possible 738 SCJ (77%), as shown in Table 5.1.

SCJ	% (n)
Left	37 % (272)
Right	40 % (298)
Not visible left	13 % (97)
Not visible right	10 % (71)
Total	100% (738)

Table 5.1 % and number (n) of SCJ assessments for both genders combined.

For the majority of patients (51%), the reason for taking the chest x-ray was not specified. Of the remaining subjects, 30% were due to trauma or for screening for TB and 20% were due to systemic conditions including cystic fibrosis, TB, lung cancer and chronic obstructive airway disease. The number, mean, SD, SE and range of age of attainment for each stage of SCJ by gender and comparison between genders are shown in Table 5.2. For subjects with the same stage for left and right SCJ, only one side was analysed, but if an individual had two different stages, both were included. This resulted in a total of 434 SCJ to be analysed.

Stage	Gender	n	Mean age of attainment in years	SD	SE	Range	P value
1	Male	10	15.5	2.6	0.8	8.3 - 17.8	0.3
	Female	3	17.1	2.2	1.3	15.8 - 19.7	
2	Male	13	19.7	5.5	1.5	15.2 – 32.0	0.8
	Female	11	19.3	1.2	0.3	16.7 - 21.1	
3	Male	45	23.7	4.4	0.6	15.2 - 33.5	*0.01*
	Female	42	21.4	4.1	0.6	15.5 - 33.5	
4	Male	82	29.0	4.5	0.5	16.5 - 35.9	0.6
	Female	106	28.7	4.1	0.4	19.2 - 35.4	
5	Male	44	30.9	4.0	0.6	22.6 - 36.3	1.0
	Female	78	30.9	3.6	0.4	21.5 - 36.0	

Table 5.2 Number, mean and median age of attainment, range and p value of paired t tests of SCJ for males and females. Significant values in italics.

The most common stage for both genders was stage 4, with stages 1 and 2 being least common. This meant that even though 369 subjects (and 434 SCJ) were assessed, the actual ‘n’ per stage by gender was much lower, a similar problem to that found when comparing TDS. There were no statistically significant differences between right and left sides, so results for both sides were combined.

In general, the mean age of attainment for each stage was greater for males than females, although the difference was slight. The only stage statistically significant between males and females was stage 3 (p=0.01). The SD for most stages was wide, ranging from 1.2 to 5.5 years, and combined with the small numbers per stage, resulted in large SE.

Figure 5.5 shows a graph of the mean age of attainment against SD for the five stages, with the upper line representing males and the lower line females. The SD for stages 1, 3-5 were similar for both genders, but stage 2 increased in SD for males, and decreased for females.

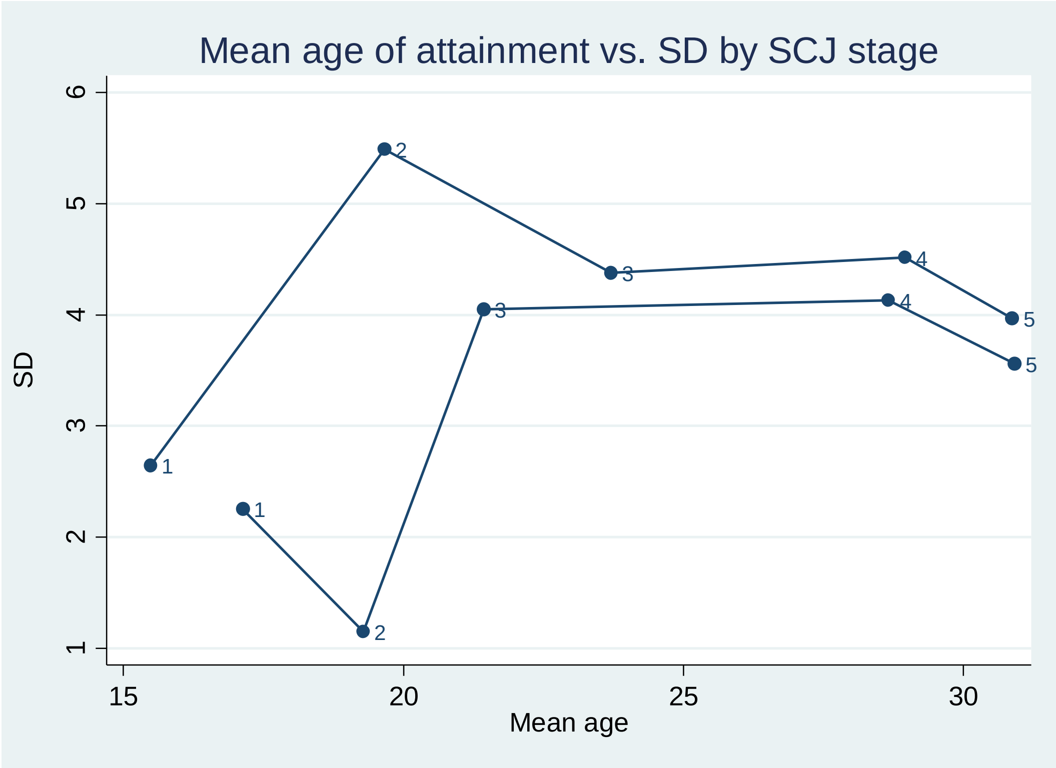


Figure 5.5 Connected scatter plot of mean age of attainment of SCJ vs. SD by stage and gender. Top line represents males, bottom line represents females.

5.2.1.2 Reproducibility of the SCJ method

Fifty chest x-rays were assessed twice by the PI to assess intra-examiner consistency. The kappa value for the right SCJ was 0.76 (95% CI 0.68 - 0.82) demonstrating substantial agreement, and for the left SCJ the value was 0.85 (95% CI 0.77 - 0.87) indicating almost perfect agreement.

In x-rays between two examiners, the kappa value for inter-examiner agreement for the right SCJ was 0.56 (95% CI 0.49 - 0.65) indicting moderate agreement, and 0.77 (95% CI 0.67 - 1.00) for the left SCJ indicating substantial agreement.

5.2.2 Root Canal Width

In total, 255 DPT's (166 males, 66%) were assessed for Root Canal Width, with the distribution by sex and grade shown in Table 5.3. For the majority of subjects, the permanent molars on the left side were graded 1 (or 4 if the third permanent molar was missing). This meant that the age of attainment for these grades had a wide range (for grade 1 from 13.7 to 35.9 years for males), which was reflected by the SD (4 years). Again, the small ‘n’ and large SD resulted in large values for SE. Apart from grades 1 & 4, the numbers in the other grades were small, meaning there was low power to detect a true difference between genders, although grade 4 was close (p=0.06).

Grade	**Gender**	**n**	**Mean age of attainment (years)**	**SD**	**SE**	**Range**	**P value**
1	Male	77	18.0	4.2	0.5	13.7 – 35.9	0.8
	Female	23	18.3	4.2	0.9	13.2 – 32.4	
2	Male	11	19.3	2.5	0.8	15.7 – 22.6	0.3
	Female	6	21.1	4.5	1.8	17.9 – 30.1	
3	Male	6	19.7	2.5	1.0	16.8 – 22.7	0.2
	Female	2	24.7	8.3	5.8	18.8 – 30.5	
4	Male	71	14.3	5.0	1.0	8.0– 33.5	0.06
	Female	50	12.8	2.8	0.7	6.8 – 20.9	
5	Male	4	27.2	8.9	4.5	14.6 – 34.9	0.1
	Female	2	13.1	7.5	5.3	7.8 – 18.5	

Table 5.3 Count, mean age of attainment, SD, SE, range and paired t tests of RCW by gender

Although stages 1 & 4 were similar (both showing LL6d<LL7d, but grade 1 also including LL8d), the mean ages of attainment were approximately 5 years apart, demonstrating the need to consider subjects with and without third permanent molar teeth separately.

The box plots of RCW grade by age for males (Figure 5.6) illustrate the differences between grades 1 & 4, and 3 & 5, with the disparity in median age, and range of values. Figure 5.6 shows that stages 1 and 4 had several outliers, indicating the variation within these grades. Grade 5 had the widest interquartile range and oldest median age.

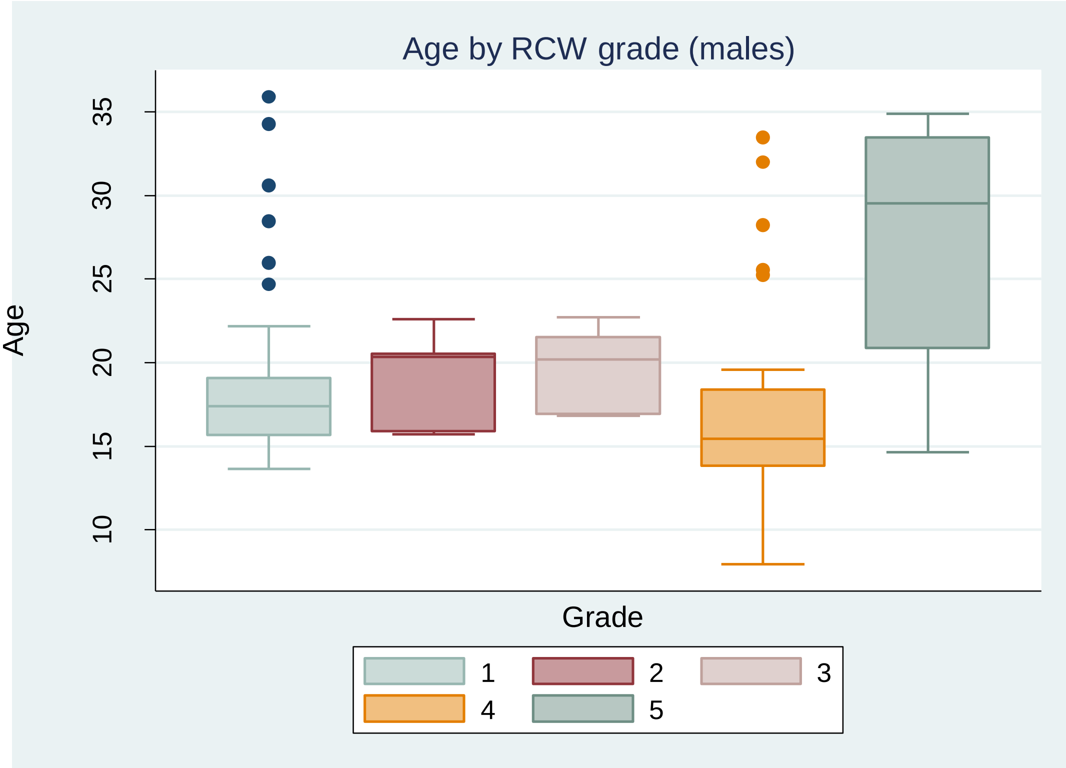


Figure 5.6 Box plot for grades of RCW for males: box represents interquartile range, horizontal line in box represents median, whiskers represent extremes, and ● represent outliers.

Due to the small numbers of females, the box plot for females shows extreme values only for grades 1 & 4 (Figure 5.7), and again shows the discrepancy between the median ages and range of values for these two grades.

Figure 5.7 Box plot for grades of RCW for females: box represents interquartile range, horizontal line in box represents median, whiskers represent extremes, and ● represent outliers.

5.2.2.1 Reproducibility of the RCW method

Fifty DPT's were assessed twice (with a one month period between the two assessments) by the PI to assess intra-examiner agreement. The kappa value was 0.84 (95% CI 0.73 - 0.91) indicating almost perfect agreement. The inter-examiner agreement was determined by the PI and a second investigator assessing the same 50 DPT's , with a kappa value of 0.7, demonstrating substantial agreement.

5.2.3 Comparison of DA, RCW and SCJ

5.2.3.1 Weighted average method

The 25 subjects with both DPT's and chest-x-rays were analysed using data from the DAA database for ages of attainment for TDS, SCJ and RCW. There were 19 males and 6 females, (age range 8 to 35 years). The mean ages of attainment were compared (Table 5.4), with the estimated mean ages for DA SCJ, RCW and their average EA shown. The blank boxes for 17 subjects (including all 6 females) in the DA column indicate there were no permanent teeth still developing, therefore DA could not be calculated. The blank box in the RCW column was due to the second permanent molar not developing sufficiently to determine RCW.

Subject	**Gender**	**CA**	**DA**	**SCJ mean age (grade)**	**RCW mean age (grade)**	**EA**
1	M	17.0	15.9	15.0 (1)	19.3 (2)	15.8
2	M	22.4		23.6 (3)	18.0 (1)	20.8
3	M	20.5		20.1 (2)	19.3 (2)	19.5
4	M	19.3	17.7	20.1 (2)	18.0 (1)	17.8
5	M	18.8	17.5	23.6 (3)	14.3 (4)	17.5
6	M	21.5		23.6 (3)	19.7 (3)	22.6
7	M	35.9		29.0 (4)	18.0 (1)	24.3
8	M	15.6	17.5	15.0 (1)	14.3 (4)	17.4
9	M	28.4		29.0 (4)	18.0 (1)	24.3
10	M	22.6		29.0 (4)	19.3 (2)	26.8
11	M	18.7	17.6	20.1 (2)	19.3 (2)	17.7
12	M	8.3	8.1	15.0 (1)		8.1
13	M	34.9		31.5 (5)	27.2 (5)	31.4
14	M	32.0		20.1 (2)	14.3 (4)	15.1
15	M	19.7		23.6 (3)	18.0 (1)	23.6
16	M	17.7	16.2	20.1 (2)	18.0 (1)	16.2
17	M	16.5	17.1	29.0 (4)	18.0 (1)	17.1
18	M	25.6		23.6 (3)	14.3 (4)	19.1
19	M	19.6		23.6 (3)	14.3 (4)	19.1
20	F	27.2		28.5 (4)	12.8 (4)	21.8
21	F	29.2		28.5 (4)	18.3 (1)	27.2
22	F	32.5		21.2 (3)	18.3 (1)	21.2
23	F	21.1		28.5 (4)	18.3 (1)	27.2
24	F	30.5		21.2 (3)	21.1 (2)	21.2
25	F	23.5		28.5 (4)	24.7 (3)	28.5

Table 5.4 Mean ages of attainment in years for DA, SCJ and RCW for 25 test subjects

A Bland - Altman plot showed poor agreement between EA and CA (r = 0.60), and increasing scatter with increasing age (Figure 5.8). The mean difference between EA and CA was -2.3 years (SD 5.5), and the 95% limits of agreement ranged from -13.0 to 8.4 years, as indicated by the red lines. There is an outlier beyond the red lines, but no error or underlying medical condition was noted for the male subject (no. 14).

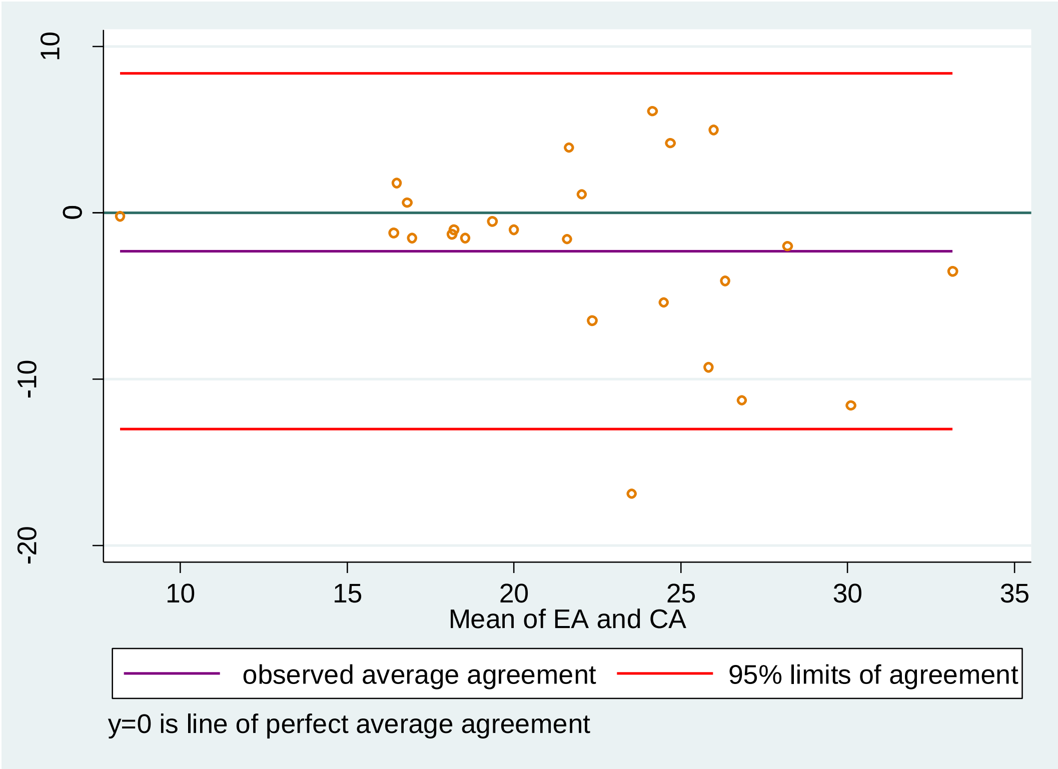


Figure 5.8 Bland - Altman plot of EA and CA

CA was compared to DA, EA and SCJ & RCW age to see if weighted average improved on the age derived from the separate assessments (Table 5.5). DA underestimated CA in 75% of the cases, SCJ in 36% and RCW in 80%. For the 8 subjects where DA could be calculated, EA was closely related to DA as expected, as the SE for DA was less than SCJ and RCW age, and the larger the SE, the smaller the resulting influence on the weighted average. When DA could be calculated, it was almost identical to EA, as shown by the columns for DA – CA and EA – CA, demonstrating that if an individual still has teeth developing, combining markers does not improve the age estimation.

For the seven subjects with DA as well as SCJ, DA was closer to CA for 6/7 subjects (85%), meaning that DA was more accurate than SCJ. RCW was closer to CA than DA for 4/7 subjects (57%), which suggested that RCW was a good predictor of age. However the wide age range for each grade of RCW meant that the difference between RCW –CA could vary by as much as 17 years, indicating that the reliability of this method is poor.

SCJ was closer to CA than RCW for 16/25 subjects (64%), indicating that SCJ was a better predictor of age than RCW.

Subject	Gender	CA	DA-CA	SCJ - CA	RCW - CA	EA-CA
1	M	17.0	-1.1	-1.9	2.4	-1.2
2	M	22.4		1.2	-4.4	-1.6
3	M	20.5		-0.4	-1.1	-1.0
4	M	19.3	-1.6	0.8	-1.3	-1.5
5	M	18.8	-1.3	4.8	-4.5	-1.3
6	M	21.5		2.0	-1.8	1.1
7	M	35.9		-6.8	-17.8	-11.6
8	M	15.6	1.9	-0.6	-1.3	1.8
9	M	28.4		0.6	-10.4	-4.1
10	M	22.6		6.4	-3.3	4.2
11	M	18.7	-1.1	1.4	0.7	-1.0
12	M	8.3	-0.2	6.7	-8.3	-0.2
13	M	34.9		-3.4	-7.7	-3.5
14	M	32.0		-11.9	-17.7	-16.9
15	M	19.7		3.8	-1.7	3.9
16	M	17.7	-1.5	2.4	0.3	-1.5
17	M	16.5	0.6	12.5	1.5	0.6
18	M	25.6		-2.0	-11.3	-6.5
19	M	19.6		4.0	-5.3	-0.5
20	F	27.2		1.4	-14.4	-5.4
21	F	29.2		-0.7	-10.9	-2.0
22	F	32.5		-11.3	-14.1	-11.3
23	F	21.1		7.4	-2.8	6.1
24	F	30.5		-9.3	-9.4	-9.3
25	F	23.5		5.1	1.2	5.0

Table 5.5 Comparison of CA with EA, DA, SCJ & RCW ages for 25 subjects.

5.3 Discussion

In previous chapters the difficulty of estimating DA in young adults with no developing permanent teeth was highlighted. This chapter explored other methods of estimating age in these individuals, in particular the use of SCJ and RCW. Several difficulties were encountered during this phase of the study and these will now be discussed.

5.3.1 SCJ

Initial training with a consultant radiologist was performed on dedicated x-ray viewers in a darkened room. Despite this, it was extremely challenging to assess the SCJ due to the superimposition of the vertebrae and positioning of the patients. To improve visibility, it was decided to restrict the study to digital chest x-rays which provided a clearer image. Even using digital chest x-rays, only 45% of the available images could be assessed and graded. However, the problem of accurately assessing chest x-rays was not restricted to this study, with a FDA study reporting that over 40% of radiographs were considered inadequate by a panel of radiation physicists and physicians (www.chest-xray.com).

In addition, 20% of patients in the sample were systemically unwell, with conditions such as cystic fibrosis, TB and cancer. This may have influenced the mean ages of attainment for SCJ obtained, as nutritional and hormonal disturbances are known to affect skeletal maturation (Melsen et al 1986). Another shortcoming of this investigation was the lack of information regarding ethnicity, as the data were collected retrospectively. Ideally the investigation would have been prospective on healthy patients; however the ethical implications of exposing individuals to radiation simply for the purposes of research make this impossible.

The dose of a conventional chest x-ray is 0.1mSv, which is the equivalent of 10 days of natural radiation (www.fda.gov). A large sample of healthy subjects of known gender and ethnicity would be required to produce reference ranges for the populations in question, with the benefits to the individual subjects being questionable. For this reason, the study was restricted to patients requiring chest x-rays for medical purposes. This is a clear limitation of the study as the sample is not representative of the general population.

The mean ages of attainment for this study and others are shown in Table 5.6. The mean ages in the present study were greater then those reported by Schmeling et al (2004) and Schulz et al (2005), and the SDs were larger for all stages. This was due to the narrower age range in these two studies (16-30 and 15-30 years respectively). The subjects in these studies were restricted to those suffering trauma or undergoing chest examination for screening purposes, and therefore it could be assumed that the patients were not suffering from any disease that might affect their skeletal development.

Stage of SCJ	**Gender**	**mean**			**SD**		
		Present study	Schmeling (2004)	Schulz (2005)	Present study	Schmeling (2004)	Schulz (2005)
2	Male	20.1		18.9	5.9		1.7
	Female	19.5		18.2	1.2		1.6
3	Male	23.6	20.8	20.9	4.3	1.7	1.9
	Female	21.2	20.0	20.5	4.0	2.1	2.7
4	Male	29.0	26.7	25.2	4.4	2.3	2.7
	Female	28.5	26.7	25.1	4.1	2.6	2.8
5	Male	31.5	28.5	27.6	3.8	1.5	2.3
	Female	31.0	29.0	27.4	3.5	1.4	2.3

Table 5.6 Comparison of SCJ between present study, Schmeling et al (2004) and Schulz et al (2005). (stage 2 was not reported for Schmeling et al).

Some authors have suggested that ethnicity had little effect on maturation of the SCJ (Schmeling et al. 2006; Meijerman et al. 2007), although this has been disputed by others (Clarot et al 2004). It seems unlikely that ethnicity would have no effect on maturation of the SCJ, when its effect on bone and tooth development has been demonstrated. Unfortunately, as the ethnicity of the sample population for the SCJ study was not known, any meaningful differences due to ethnic group cannot be investigated.

The only stage that was significantly between genders was stage 3, reflecting findings of a previous study looking at the ossification of the SCJ on radiogrpahs (Schmeling et al 2004).

The lack of an upper limit for stage 5 for age estimation has not been explored by previous authors. It should not be included in reference tables for mean ages of attainment of SCJ (in the same way that stage H is excluded). It may not have be considered as a problem for age estimation of young adults, as most people around the 18 year threshold are likely to be stage 1 or 2. Nevertheless, if stage 5 is to be included in reference tables, the data should be censored and median ages of attainment of the censored data displayed.

5.3.2 RCW

The advantage of assessing the RCW was that it did not require any further x-ray exposure to the patient, and allowed extra information to be ascertained from the DPT. For this method, a technique was required that could be used on digital images, as most radiology departments are now using digital systems. Previous studies have used traditional acetate radiographic films and callipers (Kvaal et al. 1995) or digital DPT using software, such as Adobe Photoshop (Adobe Systems Incorporated, San Jose, CA, USA) to measure ratios of pulp/tooth width and length (Bosmans et al. 2005; Paewinsky et al. 2005; Cameriere et al. 2008). The magnification of 3-10% on the left side of the mandible noted in DPT's (Sapoka & Demirjian 1971) is accounted for in these studies by stating that ratios are used, but this may not account for differences in positioning and angulation of developing teeth. The intra-examiner agreement was generally reported as not significantly different (k values were usually not given, except for a value of 0.83 in the study by Cameriere et al 2004), but inter-examiner agreement was not measured. The accuracy of these techniques was tested on an independent sample in only one method (Cameriere et al. 2007), therefore the validity of the techniques cannot be confirmed.

Additionally, one of the techniques required 30 individual points (Cameriere et al. 2004), which could be time consuming and the software may not be readily available. For these reasons, it was decided to employ a subjective method of assessing the relative width of the distal root canal, which was easy, reproducible, would not require any additional software or extensive training and could be employed to assess several subjects at a time.

Although the RCW method demonstrated good intra and inter-examiner agreement, and appeared to be closer to CA than DA for 4 of the 7 subjects used for estimating age, the wide range of ages for each grade meant that it did not provide greater accuracy for age estimation. Clearly this meant that with such a large margin of uncertainty, the RCW method did not improve the accuracy of age estimation, and was not useful for age estimation of living children or young adults of uncertain age.

5.3.3 Combination of DA, RCW and SCJ

The Study Group on Forensic Age Diagnostics for age estimation of living individuals recommends the use of SCJ as well as DPT's and x-rays of the left hand (Schmeling et al 2006). However, no studies have been published to compare combinations of the above techniques on age estimation. For this reason, the combination of DA, SCJ and RCW was investigated in a small sample of subjects that had suffered trauma and therefore had both DPT and chest x-rays taken for medical purposes. This resulted in more males than females. The main shortcoming of the sample was the small size (n=25) which meant that statistical analysis was limited. Ideally a larger sample, of known ethnicity and more with permanent teeth still developing would have allowed for better comparison of the 3 methods.

The difficulty was identifying subjects with both DPT and chest x-rays taken at the same time, as these radiographic views are rarely required together, and usually as the result of trauma. To widen the sample size, radiographs taken at different times could have been included, but this was not ideal, as it was not clear how long an interval between the DPT and chest x-ray was acceptable before affecting the age estimation.

The major problem encountered in the literature was how to combine the measurements in an individual to obtain a pooled estimated age. The technique of weighted average, which was used to calculate the DA, was extended to include SCJ and RCW measurements. The results showed that the estimated age was more closely correlated to DA than the other variables, due to smaller SE, as discussed earlier (section 5.2.3.1). However this study showed that the combined weighted averages do not improve the age estimation compared to DA alone, or SCJ mean age of attainment if DA cannot be calculated.

From this preliminary investigation, it would appear that for the purposes of age estimation in a child or young adult, if the individual has permanent teeth developing, using DA is more accurate, resulting in a smaller SD. For individuals with mature permanent teeth, assessment of the SCJ can be a useful predictor for age, although the margin of uncertainty is wider, and variation larger, as reflected by the greater value of SD for each of the stages of SCJ. The use of RCW does not improve age estimation for subjects of unknown age, due to the wide margin of uncertainty.

6. Discussion

6.1 Summary of findings

This study has explored estimation of age using dental development for living subjects. Four methods (Haavikko, Demirjian, Mörnstad and weighted average) were evaluated initially on 50 subjects. The weighted average method was shown to compare favourably and warranted further investigation. The DAA database was developed further and the effect of 12 or 8 stages of TDS on the accuracy of dental age estimation, using the weighted average method, were compared using 2426 subjects in the DAA database. It was found that there was no difference between 12 and 8 stages for mean difference between DA and CA, though better reproducibility was observed for 8 stages. The measure of agreement between 12 and 8 stages demonstrated that the discrepancy between the stages increased with increasing age.

The fact that there was no difference between DA and CA between 12 and 8 stages was surprising, as increasing the number of stages should decrease the time interval between stages and therefore increase the accuracy of DA estimation. The average time interval between TDS was 1.4 years for 8 stages and 1.0 for 12 stages, demonstrating that there was a slight difference between the two staging systems. However comparing the mean difference of DA – CA individually showed that whilst 12 stages were more accurate for some subjects, 8 stages were better for others, resulting in no difference between both stages overall.

There has been much debate in the literature as to whether having more stages improves the accuracy and precision of dental age estimation (Nortjé 1983; Kullman et al 1992; Gunst et al 2003; De Salvia et al 2004; Olze et al 2005). The high level of intra and inter-examiner agreement reported for Demirjian's 8 stage method (Olze et al 2005; Dhanjal et al 2006; Meinl et al 2006; Soo-Hyun et al 2009) means that this system is the most recognised for DAA. The better reproducibility of 8 stages as compared to 12 stages in this study, equal ease of use and time taken to complete assessments, meant that 8 stages was also preferable to 12 for the weighted average method.

The accuracy of DA estimation compared to CA was investigated in children under and over 10 years of age, using 8 stages, and found that DA overestimated age for <10 years, but underestimated age for >10 years. To investigate this further, the subjects were subdivided into year intervals, and it was found that the mean difference DA – CA was not related to the 10 year threshold, with under and overestimation of DA noted from 3 – 18 years for both genders. The number of teeth developing, and the diminishing relationship between CA and maturity markers with increasing age may explain the discrepancy seen when comparing children under and over 10 years.

As it could have been considered biased to test DA on the same sample from which the reference data set was derived, the 8 stage weighted average method was tested on an independent study sample of 200 subjects. The mean difference DA – CA and SD was larger than for the DAA database subjects and DA overestimated age for both genders.

The effects of gender and ethnicity on mean age of attainment of TDS, and hence on DA estimation were investigated. Females matured faster than males for all teeth (except the third permanent molars, where males matured faster than males). Comparing ethnic groups was restricted to Whites and Blacks due to the small n-tds when the data were divided by gender, and the six main ethnic groups. Blacks matured earlier than Whites for 70% of TDS in males and 80% for females, although statistical analysis was limited to the third permanent molars.

The combination of using Sternoclavicular Joint (SCJ), Root Canal Width (RCW) and DA to improve the accuracy of age estimation for young adults was examined. It was found that whilst SCJ demonstrated better accuracy than RCW, DA was closer to CA when tested on 25 subjects with both chest x-ray and DPT. Combining DA, SCJ and RCW mean ages of attainment using weighted averages did not improve the accuracy or precision of age estimation.

The close association between DA and CA in this study confirmed the findings of others, who suggested teeth exhibited better correlation to age than other markers of maturity such as bone age (Lewis and Garn 1960; Tonge & McCance 1975; Green 1961; Melsen et al. 1986). This is possibly due to the fact that tooth development is genetically controlled and less influenced by nutritional and hormonal factors than skeletal maturation (Garn et al. 1965a; Garn et al. 1965b; Pelsmaekers et al 1997).

6.2 Dental development

Radiographic assessment of dental development has been used for more than 60 years, and is able to record both the sequence of tooth mineralization, and the timing of various stages in individual teeth (Reid and Dean 2006). The advantage of using radiographs is the ability to use large numbers of subjects, either in cross-sectional or longitudinal studies, and more importantly in living individuals for age assessment. The disadvantages include the lack of information regarding the early stages of the teeth developing in the first few years of life, and the lack of resolution to distinguish near-microscopic changes in tooth growth (Reid and Dean 2006).

Histological analysis of extracted teeth is considered the gold standard, as the incremental lines in enamel allow recording of the rate of enamel formation in days rather than months or years. Whilst this technique is not appropriate for age estimation of living subjects, it is useful to compare the age at formation derived from histological and radiographic studies, to determine the accuracy of radiographic formation times. The results for crown completion in a large histological study using samples from European and Southern African origins (Reid and Dean 2006) are compared to the present study using the White and Black data for stages A – D (crown initiation to crown complete) which correspond to crown formation. It was only possible to compare the second and third permanent molars, as these were the only teeth with stage A data (premolars were excluded in the histological study). Because gender of the histological samples was not known, the results for males and females were pooled to give mean times for crown formation in the present study (Table 6.1). It was not possible to determine the crown formation of the anterior teeth, as there were no teeth with stage A for either group.

Tooth	Histological crown complete (years)		Radiographic crown complete (years)	
	European (n)	Southern Africa (n)	White (n)	Black (n)
UL7	3.3 (12)	3.2 (19)	3.4 (61)	3.5 (6)
UL8	2.8 (15)	3.2 (19)	5.3 (328)	
LL7	3.2 (16)	3.2 (17)	3.8 (46)	3.7 (7)
LL8	3.2 (15)	3.3 (14)	4.5 (323)	3.9 (52)

Table 6.1 Comparison of crown formation times between present study and Reid and Dean 2006.

There appeared to be a difference between the histological samples, with southern Africans maturing earlier than their European counterparts, although this was less marked in the molar teeth (Reid and Dean 2006). This was also observed in the present, radiographic study in the lower molars, with Blacks maturing faster than Whites. The crown formation times for this radiographic study were larger than the histological formation times quoted (particularly for the third permanent molars); this may have been due to the greater accuracy in determining the exact time the crown has formed using histological sections. In addition, as the gender of the histological study was not known, some of the differences may be attributed to gender differences between the two samples.

However, the difference may be due to the fact that comparing stages A-D is not comparable to mineralisation initiation to crown completion determined by histological section. Radiographs represent a two dimensional mesial/distal view of the tooth, rather than bucco-lingual or mesial/distal sections of the whole tooth that are available in histology. This means that discerning the exact spot where that enamel ends and the root begins, to signify crown completion, is nearly impossible on a radiograph, as is determining the thickness of enamel compared to histological section. A study by Grine et al showed that radiographs generally over-estimated enamel thickness compared to histological section (Grine et al. 2001). In addition, tooth formation stages which are not based on anatomical morphological dimensions cannot be easily compared with accurately measurable histological samples. This shows that caution is required when using cross-sectional radiographic data to determine the formation times of permanent teeth.

Nevertheless, a difference between ethnic groups was noted for crown formation and indicated that ethnicity does influence tooth development, and therefore requires further consideration.

6.3 Ethnicity

6.3.1 Recording ethnicity

Data from the hospital Patient Administration System (PAS), for the year 2003 recorded 8662 patients within the required age ranges attending the EDH. It showed the main ethnic groups attending EDH were White British, Asian and Black, with the majority being White British. In more than 50% of cases; the ethnicity was not stated or invalid. For this reason, using retrospective data recording ethnicity was considered unreliable for the purposes of this study and specific questioning of ethnicity was required prospectively. This has been a major shortcoming of previous studies which have either ignored ethnicity or based it on unsatisfactory criteria, such as geographical area or patient's names.

This situation has improved recently due to a Department of Health drive to record ethnicity data with 81% of patients attending EDH in 2008 having a valid ethnicity score recorded. In future, it should be possible to obtain ethnicity data for patients; however the problem of ethnicity classification remains.

6.3.2 Ethnicity classification

For many kinds of epidemiological research, a measure of the denomination of the ethnic group is required. For such purposes the broad based Census categories are frequently used (Aspinall 2003). Using broad categories is not without its problems, as illustrated by the Asian category; in the UK census, Asian is used exclusively to refer to people with origins in the Indian subcontinent. Asians from the pan-pacific countries are considered under the category 'Chinese'. (www.statistics.gov.uk/census2001). However, in Scotland the Asian category includes Chinese (www.scotland.gov.uk), whilst in Canada the Asian category includes South Asian (e.g., East Indian, Pakistani etc), Southeast Asian (e.g. Cambodian, Vietnamese etc) and West Asian (e.g. Iranian, Afghan etc) in addition to separate categories for 'Chinese' 'Japanese' and 'Korean' (Aspinall 2003). A similar problem is encountered when considering the Black category, with the additional connotation of skin colour and possible discrimination. Also, the use of standardised terminology can result in certain ethnic groups suffering injustice as they do not fit neatly into the nomenclature (e.g. Arabs or Jews), resulting in their under representation or invisibility in the Census (Aspinall 2002).

For this reason, the next Census in Scotland has replaced the fields for White and Black with European and African. The African field separates people into 5 regions; Central, West, East, Southern and North, as well as Caribbean. There are also fields for Asian (including Chinese), Multiple background, Arab and Other (including Traveller and Jewish ethnic groups) (www.scotland.gov.uk 2008). Whilst it is desirable for each country to tailor their Census classification for their individual ethnic communities, this does make comparison between countries difficult.

Another concern with specified categories is the limitation it places for individuals to describe themselves freely. The recommended practice for identifying ethnic group is based on the person's perception of their ethnicity. This can become especially complicated for people of mixed ethnic background.

6.3.3 Ethnicity and race

As defined previously, ethnicity is subjective and relates to a shared cultural history. In contrast, race usually relates to presumed shared biological or genetic traits within a group and is identified by physical characteristics e.g. skin. In reality, it has been demonstrated that 90% of human genetic variation occurs within a population living on a given continent, whereas only 10% of the variation distinguishes continental populations (Bamshad & Olson 2003). A person may subscribe to a particular ethnic group because they feel they belong to that group, but may be of different racial origin, e.g. an individual born in the UK who considers themselves White British, but whose parents are of Turkish or Eastern European Jewish ancestry. To try to account for the differences between ethnicity and race, the consent forms in this study contained a freeform field where the country of birth of both parents could be recorded.

Unfortunately, this field was not completed by all participants, and further analysis of the individual subgroups was not possible, due to the small numbers. This was a particular problem when the individual TDS were compared by ethnic group. This meant it was impossible to ascertain if ethnicity affected the age of attainment of the permanent teeth for the six main categories. The only two groups with sufficient numbers for comparison were White and Black.

6.3.4 White and Black

There was a difference between White and Black groups for certain permanent teeth (UL7, LL7 and LL5), as well as the third permanent molars. However for these teeth, Blacks developed later than Whites, that is to say Whites matured earlier than Blacks. In contrast, stages F & G for the third permanent molars showed Blacks maturing earlier than Whites, which supports the findings of other authors (Olze et al. 2007; Liversidge 2008b). A general trend for Blacks to mature earlier than Whites for most TDS (70% males and 80% females) was also observed, although numbers per TDS were too small for statistical analysis. A difference between ethnic groups for permanent teeth, excluding the third molars, is in contrast to a previous paper which stated no difference between ethnic groups (Liversidge et al. 2006). It appears strange that the third permanent molars would show ethnic differences, but not the other permanent teeth. This is the opposite of somatic growth, where Blacks mature earlier than Whites, and therefore it follows that dental development should show a similar trend.

The inconsistencies between the teeth and stages for Whites and Blacks may be due to the small sample sizes or variability of ethnicities within 'Black' grouping e.g. Black Caribbean vs. North African. These two sub groups have a totally different ethnic origin and facial morphology (most Afro-Caribbean people originate from

West Africa, whereas people from North Africa are a mix of Black African and/or Arab in origin), therefore lumping the Blacks together may mask differences between subgroups. Analysis of subgroups within the Black group was not possible in this study due to small numbers, but an MSc thesis at Kings (Moze 2009) has shown that Black Caribbean's from Trinidad matured significantly earlier than Whites from the UK. This was evident for all TDS and translated into statistically significant difference in DA estimation between the two groups.

This confirms that there is a difference between Whites and Blacks for tooth development and highlights that the influence of ethnicity must not be overlooked when considering age estimation of living subjects. although the difference of 2.5 months was not significant when averaged over all TDS, the difference between Whites and Blacks for the third permanent molars was over half a year. When the mean of DA – CA was analysed by ethnic group, it was found that DA was overestimated for Blacks and Asians for both genders. This means that an individual from either ethnic background could be judged as being older than their CA and thus may be disadvantaged. This is an important consideration when discussing the issue of unaccompanied asylum seeking children (UASC).

6.4 Age estimation for unaccompanied asylum seeking children

The particular problem of UASC arriving in the UK, and the need for establishing methods for age determination was briefly described in the introduction. When UASC arrive at a border port or screening centre, they are required to state their age, if known, and provide supporting evidence to confirm this. If such documents are missing, considered unreliable, or if the immigration officer has any doubts about the age of the applicant, this is regarded as an age disputed case. If the applicant is considered less than 18 years of age, they should be treated as a child, and placed with a local authority until their case is processed. Local authorities have a statutory duty to provide services necessary to safeguard and promote the welfare of all children deemed to be 'in need' under the provisions of the Children Act 1989 (Crawley 2007).

6.4.1The process of age assessment

The local authority where the child/young person is placed should arrange for an age assessment to be undertaken. This involves the assessment of physical and intellectual development through the use of interviews. Whilst there are currently no statutory guidelines for age assessment in the UK, guidelines have been developed by two social service departments, Hillingdon and Croydon, which have had to deal extensively with UASC. These guidelines advise the use of two experienced professionals who interview the applicant over a period of time, in order to assess the appearance and demeanour of the applicant – this is said to be a "Merton compliant assessment" (Collins 2009). The age assessment will then either confirm the child is their stated age, the information being forwarded to the Home Office for the records to be amended and the child to be given discretionary leave to remain in the UK until their 18th birthday, or they will be considered over 18 years of age and detained as an adult in Oakington detention centre whilst the age dispute appeal process is performed (Crawley 2007). There are obvious child protection issues with either placing a child in an adult setting, or placing an adult in the company of other children, both of which are inappropriate.

6.4.2 Age disputes

The Home Office states that "The Border and Immigration Agency (BIA) will dispute the age of an applicant who claims to be a child but whose physical appearance and/or general demeanour very strongly suggests that they are aged 18 or over, unless there is credible documentary or other persuasive evidence to demonstrate the age claimed. In borderline cases it is the BIA's policy to give the applicant the benefit of the doubt and treat them as a child" (Collins 2009). However, in reality a culture of disbelief exists, with the Home Office of the view that the primary reason for the increase in age disputes is due to adults claiming to be children (Crawley 2007). Immigration officers rely on a visual assessment of the physical appearance of an applicant before deciding if this is an age disputed case or not. The problem with an over-reliance of physical appearance is that it is a poor indicator of chronological age. Many UASC have been brought up in conditions of poverty and may have had to undertake manual labour which may make them appear older than they are. In addition, ethnic or racial differences, such as dark facial hair, may make individuals appear older than they actually are, when compared with the physical characteristics of children who have grown up in the UK (Crawley 2007).

If physical appearance is not considered a good way to assess CA, a Merton compliant assessment by two social workers is also not ideal. Some legal representatives and voluntary sectors workers have expressed concern that where social services are involved in the age assessment of those whom they must ultimately take responsibility for, a conflict of interest arises. “Many social workers have expressed reservations about their role in age assessments. These reservations arise from the fact that age assessment, unlike current social practice, does not engage a range of professionals and is approached in a single rather than multi-agency framework. The absence of multi-agency working, statutory guidance and lack of support and training for social workers undertaking age assessments has the effect of increasing the burden of responsibility” (Crawley 2007).

The quality of the age assessment process undertaken by social workers was judged as being often poor. There is also evidence that social service assessments of age frequently reflect socially constructed understandings of how children should *behave* (Crawley 2007). “UASC come from cultures and contexts in which childhood is defined in different ways and where the social, economic and political circumstances in which they live make it impossible for them to do the things that we expect children living in the UK to be able to do” (Crawley 2007).

In addition, the Merton compliant method has not been tested to ascertain the validity or precision for age assessment of UASC. There are many examples of UASC being assessed by different local authorities and results in multiple assessments contraindicating each other (Crawley 2007).

Because of the concerns highlighted above, some social service departments and legal practitioners use medical evidence in an effort to resolve disputes over age. These are most commonly undertaken by a consultant paediatrician and may include:

- Anthropometric measurements including height, weight, skin, sexual characteristics
- Non-objective measurements, such as the young person's interactions with the paediatrician
- Skeletal age
- Dental age

The role of the paediatrician in age assessments, and the usefulness of the medical assessment have been questioned recently, with a court judgement indicating that the medical evidence from a experienced paediatrician was no better than trained social workers in assessing whether a UASC was younger than 18 years (Collins 2009).

6.4.3 Concerns regarding medical assessments

The main objections to using medical assessments for age estimation are (i) there are no medical methods that can accurately estimate age, with most methods associated with a margin of error of at least two years in either direction, (ii) that these methods measure maturity and not chronological age and (iii) that the use of radiographs for age assessments, where there is no medical indication is considered unethical (Physicians for Human Rights 2003; Crawley 2007; Stern 2008 and Aynsley-Green 2009). These objections will be dealt with individually below.

6.4.4 The reliability of measurements to determine age

In a report submitted to the courts regarding the use of maturity markers to determine age, the following list was described:

"Before a specific measurement of a child's growth and maturity could have a reliable accuracy attached to it as one which has been scientifically correlated with age, it would be necessary for the measurement in question to have been subjected to a series of processes accepted by scientists.

For any clinical measurement these are:

1. The measurement must be carried out in a standard way and take into account known genetic patterns.

2. Many of the same measurements must be carried out on a large population.
3. These data must be analysed statistically, so as to generate means or medians and standard deviations or errors.
4. The data and their analyses should be published, in order that they are subjected to peer review. This is a critical step in the confirmation of scientific validity.
5. The whole process of measurements should be repeated on a similar population, so as to validate the original data published.
6. It would be necessary to repeat the validated measurement on an ethnically different population, in order to establish the presence or absence of ethnic variability.
7. Finally, in order that any of these clinical measurements might be employed to estimate age, it would be necessary for all these observations to be carried out on populations of children and young people of known age."

(Stern 2008)

(The above list is referenced in the report by Stern credited to D Altman 'Practical statistics for medical research', but the list was not located despite contacting Dr Stern).

The inherent uncertainty when using anthropometric measurements, psychological evaluation or using skeletal markers for determining the age of UASC has been described. The depth of literature in the field of DAA has demonstrated that dental development is more accurate than other markers. In particular, the weighted average method used in this study fulfils all of the criteria stated above.

It has been derived from a large population of known CA, separated by gender and ethnic origin and tested on an independent sample to determine validity. The data has been peer reviewed and published (Roberts et al 2008; Mitchell et al 2009; Peiris et al 2009). The SD of the mean difference DA - CA is approximately one year, which improves on the ±2 years quoted extensively in the literature (Crawley 2007; Stern 2008; Collins 2009).

6.4.5 Maturity vs. CA

A criticism of age assessment methods is that they measure maturity, i.e. how far a specific characteristic in a person has progressed towards full expression, or adulthood (Stern 2008). These are then compared with standards of normality for the population the individual comes from, or other reference ranges if these are not available. While different markers of maturity may have differing time spans and units, depending on what is being measured, in practice all maturity data are linked to CA, in order to provide meaningful information about an individual, as they are closely related. Whilst it is true that there can be considerable individual variation between maturity and CA, particularly due to gender and ethnicity, dental development has been shown to be less affected by nutritional and hormonal disturbances and correlates closely to CA.

6.4.6 Use of radiographs for age assessment

The Royal College of Paediatrics and Child Health has expressed its opposition to the use of x-rays for non-clinical purposes, a view that is echoed by the former Children's Commissioner for England (Crawley 2007). It is considered unethical to irradiate a child or young adult for age assessment purposes and without informed consent. Clearly informed consent is required for any intervention, and a radiograph should not be undertaken without a full explanation and the express wish of the applicant to have a medical age assessment to support their claim that they are under 18 years of age.

However, the claim that taking radiographs for DAA is unethical has been challenged, with the process likened "to the process of medicolegal reports, where a decision about liability has to be assessed with no clinical benefit to the subject" (Roberts and Lucas 2009).

The concern of unnecessary exposure of vulnerable children or young adults to radiation is an important consideration and requires an assessment of the risk involved. The dose of a DPT is 26µSv compared to a dose of 8mSv for a chest CT (www.fda.gov). The health risks from a DPT due to the emitted radiation dose are thus 100 times smaller than other everyday risks, such as car or public transport, and equivalent to a 3.5 hour intercontinental flight (Ramsthaler et al 2009). The authors of this study concluded "the resulting risks from using x-rays in age determination procedures (with the exception of CTs on sternoclavicular joints) is very low in comparison to other life risks, and considered justifiable" (Ramsthaler et al 2009).

6.4.7 A holistic approach to age determination

The Immigration Law Practitioners Association and the Children's Commissioner for England both advocate a holistic approach to age determination for UASC. "Medical evidence may be an important part of the picture in the assessment of age but should not be relied upon in isolation from other evidence and information. Age assessment should be a holistic process in which views of different types of evidence provided by different kinds of professionals are taken into account. This is the only way in which ongoing disputes over the assessment of age can be avoided" (Crawley 2007). At present, there is no single method which can predictably and accurately assess age, but the reality is that UASC require age estimation, so that appropriate services can be provided. Dental age assessment has a place for instances when the determination of age is not clear and age is disputed.

6.4.8 Is the weighted average method the answer?

This study has investigated if dental age assessment is more reliable than skeletal age. The weighted average method shows promise, in both increasing the statistical precision of the estimated age and ability for other investigators to contribute to the DAA database. However, the small numbers of different ethnic groups for each TDS limit the usefulness of the method for UASC at present, particularly the lack of data for children and young adults of African and Middle Eastern origin – ideally reference ranges are required for each nationality, ethnic group or identifiable human group by gender.

6.5 Shortcomings of the study

6.5.1 Sample

A criticism of a cross sectional sample based at a dental hospital is that it is not representative of the general population. In particular, EDH which is a specialist referral centre may see more complex patients than prevalent in the population. Whilst it is acknowledged that the ideal sample would be randomly selected from the population of interest, ethical considerations prohibit the taking of dental radiographs solely for the purposes of research. This means that such studies must be restricted to dental centres or preferably hospitals, where a large number of subjects are available. Dental caries is a disease that mainly affects children from socially deprived backgrounds, whereas patients requiring orthodontic treatment have low caries rates. Therefore by choosing patients from both departments, a reasonable cross section of the general population attending a dental hospital is achieved, although it is acknowledged that this may not be representative of the general population. Including patients attending KCH, which is a secondary referral centre and therefore may see fewer complex cases, and serves a larger Black ethnic population, also improved the representativeness of the sample to the general population in London.

6.5.2 Distribution of TDS

There have been many studies investigating dental development, as shown in tables 2.2 (section 2.1.5.2) and 2.5 (section 2.9), with sample sizes ranging from 51 – 3224 subjects. Very few studies describe the distribution of subjects per tooth, and even fewer the number per TDS, when subdivided by gender and ethnic group. This means that for most TDS, except the third permanent molars, the numbers are low and therefore the resulting statistical power is low. None of the previous studies have highlighted this problem, and this only became apparent during the present study once the data were analysed by TDS. To combat this, subjects would need to be selected by TDS specific age bands, gender and ethnicity to ensure appropriate numbers. It is not possible to do a sample size calculation to determine the total number required, e.g. the WHO advice of 100 per TDS would require 21, 600 subjects.

Another problem was recording the mineralization of the early stages of the permanent teeth, as the first permanent molars and central incisors start developing at birth. Primary teeth do not usually erupt before six months of age; therefore there is no indication to radiograph the jaws at birth. This means we have to rely on histological samples or perinatal pathology images, which are usually based on children that have died due to medical complications and therefore are not representative of normal children. This is not a problem for forensic use, but may not be representative of healthy children.

6.5.3 Stage H

In section 4.1.6 the problem of stage H and the fact that it cannot be used in the weighted average, or any other method of DAA, because there is no upper limit for this stage, was discussed. This is the same problem when considering stage 5 for the SCJ and any system where the last stage is open-ended. The way this is overcome in DAA methods, is to exclude any teeth with stage H from the final analysis. This produces bias, by ignoring teeth that have fully matured and including developing teeth only, thus underestimating DA. Censoring of stage H does not fully remove the bias, as it merely sets an artificial limit for stage H (be this the last occurrence of stage G or using 3 SD). Because of the difficulty of dealing with stage H, it is appropriate to exclude it from DA estimation, but the bias remains. It could be argued that the bias is in the individual's favour, as DA is underestimated rather than overestimated, so that the age estimation does not have a detrimental effect for an UASC.

6.5.4 Weighted average method

This method was devised to address the deficiencies of previous methods of DAA. The use of 95% CI to indicate the measure of the uncertainty of the estimate gave an indication of the range of possible values for a given combination of developing teeth. However, it must be remembered that this is the 95% CI of the sample population mean age and not the individual. To apply this CI to the individual would imply a degree of precision that is incorrect and would exaggerate the accuracy of the weighted average method.

In addition it assumed that the TDS were not correlated, which clearly they are in an individual. This means that the variation for an individual would be much larger than the 95% CI of the population mean, possibly as much as five times wider (Cole 2008). To account for this correlation required advanced algebra and statistical analysis, but was outside the remit of this study. Obtaining an estimated mean age for a subject is not particularly helpful without some measure of the uncertainty for this estimate. Using the population mean age 95% CI is clearly inappropriate, therefore the use of probabilities is required.

The issue of whether an individual is under or over 18 years of age is an important consideration for child protection and legal reasons. Whilst an estimated age can be assigned using the teeth and/or SCJ, the degree of uncertainty of this estimate cannot be determined, as explained above. At present, the best indication that can be given regarding the uncertainty of age estimation is by using the probability that a person is under or over 18 years of age. The probability around the 17-19 year-old threshold was determined, but the small numbers meant no meaningful results could be obtained.

6.6 Strengths of the study

The use of the weighted average method meant an estimated mean age could be derived using any combination of permanent teeth still developing, either maxillary or mandibular, including the third permanent molars. The combination of skeletal and tooth development using SCJ and DAA has not been described previously in the literature, although it is recommended by the Study Group on Forensic Age Diagnostics for age estimation of living individuals (Schmeling et al 2006). The weighted average method lends itself well to combining several variables to give an overall estimated age, and provides a simple method to compare maturity markers in an individual. It was hypothesised that combining markers would improve the accuracy and precision of age estimation; particularly for young adults, when the third permanent molar may be the only tooth still developing. However this preliminary study indicated that DA is the best predictor of age.

6.7 Future work

Early stages of some of the permanent teeth, i.e. the incisors and first permanent molars, were not represented in the present study, as not many radiographs are taken in very young children. Anecdotal opinion from clinicians has indicated that the tooth atlas seems to be delayed compared to the development stages seen clinically and this area needs to be expanded, so that reference standards for all permanent teeth can be produced to update the tooth atlas tables which are based on data from small histopathological samples of 25 deceased European children from 0-15 years (Logan and Kronfield 1933). A recent Tooth atlas (AlQahtani 2008) has been developed using 72 prenatal and 104 post natal remains and data from 528 living subjects, which improves on the Logan and Kronfield study. However access to 502 perinatal pathology CT scans allows for further investigation of tooth formation of early developing permanent teeth.

In order to produce reference data for each ethnic group by gender, collaboration with international investigators is required. This will require training, both in the method and the use of the DAA database. The benefit of using the Access database is that data from other investigators can be incorporated into the main database, so that queries can be run for large numbers of subjects. Ideally the radiographs should be collected from a primary care / community setting as this would be more reflective of the general population. With the increase in digital radiography, it may be possible to ask general practitioners to email images for assessment (subject to appropriate ethical approval and data protection).

To explore the correlations between TDS and to determine the 95% CI of the estimated DA of an individual, and thus the uncertainty of the estimate will require further analysis by a statistician. In addition, the n-tds around the 17-19 year-old age range needs to be expanded, so that the use of probabilities to determine the 18 year-old threshold can be performed.

The mean age of attainment per stage of SCJ and the effect of ethnicity requires further assessment of chest x-rays, to improve the variation and produce reference data, as SCJ appears to be a good predictor of age for subjects without developing permanent teeth.

The combination of DA and SCJ using weighted average showed promise, but due to the small numbers, analysis was limited. To improve sample size, collaboration with Maxillo-facial surgeons will be required, to identify eligible patients. This will allow statistical analysis and determine conclusively if combining maturity markers improves the accuracy of age estimation, or DA alone is the best predictor.

7. Conclusions

1. Four methods of DAA were compared against CA and it was found that the weighted average method (Roberts et al. 2008) demonstrated the smallest mean difference of DA-CA for the test sample. The SD of the mean difference and 95% CI was similar to Demirjian, indicating that the weighted average method warranted further investigation.
2. (a) Twelve vs. eight stages were compared to determine whether the number of stages affected the accuracy and precision of DA estimation, and showed that there was no difference between 12 and 8 stages, and 8 stages demonstrated better reproducibility.

   (b) This study has confirmed that dental development is closely correlated to CA, and that females mature faster than males for permanent teeth. The exception was the third permanent molars, where males matured faster than females.

   (c) There are significant differences between White and Black subjects, although the effect of other ethnic groups could not be investigated due to small number per TDS.

   (d) The degree of hypodontia in the third permanent molars was shown to be low (10-13%), with the upper teeth developing earlier than the lower. This indicated that the third permanent molar could be used for DAA. Censoring the data to determine the median age of attainment highlighted the problem of using stage
3. The combination of DA, SCJ and RCW showed that DA was the best predictor of age in an individual with permanent teeth still developing. For subjects with no teeth still developing, the SCJ can be used to estimate the age of an individual.

Publications arising from this thesis

Presentations arising from this thesis

Oral presentations

IADR 2009: **Comparison of Demirjian and Haavikko methods for Dental Age Assessment.** S Parekh

Poster presentations

IAPD 2005: **Dental Age Assessment from Dental Panoramic Radiographs using Meta Analysis**. S Parekh, G Roberts, V Lucas, A Petrie

IADR 2006: **Pilot study of a new method for Dental Age Assessment (DAA).** S Parekh, G Roberts, T Cole, A Petrie

IAPD 2007: **Dental Age Assessment of Proteus Syndrome: A Case report.** S Parekh, R Crawford and D Gill

References

A

Altman DG. 1991. *Practical statistics for medical research,* 1st edition. London, Chapman and Hall.

Anderson DL, Thompson GW and Popovich F (1975). Interrelationships of dental maturity, skeletal maturity, height and weight from age 4 to 14 years. *Growth;* **39**(4): 453-462.

AlQahtani S J (2008). Atlas of tooth development and eruption. Barts and the London School of Medicine and Dentistry. London, Queen Mary University of London. (http://www.dentistry.qmul.ac.uk/atlas%20of%20tooth%20development%20and%20eruption/index.html) Accessed February 2011.

Arany S, Iino M and Yoshioka N (2004). Radiographic survey of third molar development in relation to chronological age among Japanese juveniles. *Journal of Forensic Science;* **49**(3): 534-538.

Aspinall PJ (2002). Collective terminology to describe the minority ethnic population: the persistence of confusion and ambiguity in usage. *Sociology;* **36**(4): 803-816.

Aspinall PJ (2003). Who is Asian? A category that remains contested in population and health research. *Journal of Public Health Medicine;* **25**(2): 91-97.

Aynsley-Green A (2009). Unethical age assessment. *British Dental Journal;* **206**(7): 337. Response: Roberts GJ and Lucas V (2009). Ethical dental age assessment. *British Dental Journal*; **207**(6):251-254.

B

Baba-Kawano S, Toyoshima Y, Regalado L, Sa'do B and Nakasima A (2002). Relationship between congenitally missing lower third molars and late formation of tooth germs. *The Angle Orthodontist;* **72**(2): 112-127.

Backström M, Aine L, Mäki R, Kuusela AL, Sievanen AM, Koivisto RS, Ikonen RS and Mäki M (2000). Maturation of primary and permanent teeth in preterm infants. *Archives of Disease in Childhood. Fetal and Neonatal Edition;* **83**(2): F104-8.

BAILII. England and Wales High Court (Administrative Court) Decisions, Mr Justice Collins (2009).http://www.bailii.org/ew/cases/EWHC/Admin/2009/939.html. Accessed February 2010.

Bamshad MJ and Olson SE (2003). Does race exist? *Scientific American;* **289**(6): 78-85.

Bilgili Y, Hizel S, Kara SA, Sanli C, Erdal HH and Altinok D (2003). Accuracy of skeletal age assessment in children from birth to 6 years of age with the ultrasonographic version of the Greulich-Pyle atlas. *Journal of Ultrasound Medicine;* **22**: 683-690.

Black S and Maat G (2010). *Chapter 6: Principles of physical age estimation. In Age estimation in the living: The practitioners guide*, 1st edition, West Sussex, John Wiley & Sons Ltd.

Bland JM and Altman DG (1986). Statistical methods for assessing agreement between two methods of clinical measurement. *Lancet;* **1**(8476): 307-310.

Blankenship JA, Mincer HH, Anderson KM, Woods MA and Burton EL (2007). Third molar development in the estimation of chronologic age in American blacks as compared with whites. *Journal of Forensic Science;* **52**(2):428-33.

Bolaños MV, Manrique MC, Bolaños MJ and Briones MT (2000). Approaches to chronological age assessment based on dental calcification. *Forensic Science International;* **110**: 97-106.

Bolaños MV, Moussa H, Manrique MC and Bolaños MJ (2003). Radiographic evaluation of third molar development in Spanish children and young adults. *Forensic Science International;* **133**: 212-219.

Bosmans N, Ann P, Aly M and Willems G (2005). The application of Kvaal's dental age calculation technique on panoramic dental radiographs. *Forensic Science International;* **153**: 208-212.

Butts SF and Seifer DB (2010). Racial and ethnic differences in reproductive potential across the life cycle. *Fertility and Sterility;* **93**(3):681-90.

C

Cameriere R, Ferrante L and Cingolani M (2004). Precision and reliability of pulp/tooth area ratio (RA) of second molar as indicator of adult age. *Journal of Forensic Science;* **49**: 1319-1323.

Cameriere R, Ferrante L and Cingolani M (2006). Age estimation in children by measurement of open apices in teeth. *International Journal of Legal Medicine;* **120**: 49-52.

Cameriere R, Ferrante L, Liversidge HM, Prieto JL and Brkic H (2008). Accuracy of age estimation in children using radiographs of developing teeth. *Forensic Science International;* **176**(2-3):173-177.

Chest x-ray.com Information about chest x-rays (2000). http://www.chestx-ray.com/GenPublic/GenPubl.html. Accessed February 2010.

Chinn S, Cole TJ, Preece MA and Rona RJ (1996). Growth charts for ethnic populations in UK. *Lancet;* **347**: 839-840.

Clarot F, Le Dousseur P, Vaz E and Proust B (2004). Skeletal maturation and ethnicity. *Legal Medicine;* **6**: 141-142.

Cole TJ (2008). Hot potato topic. *British Dental Journal;* **205**(11): 581.

Crawley HF (2007). *When is a child not a child? Asylum, age disputes and the process of age assessment.* London, Immigration Law Practitioners' Association.

D

Dahllöf G, Näsman M, Borgström A, Modéer T, Forsberg CM, Heimdahl A and Ringdén O (1989). Effect of chemotherapy on dental maturity in children with hematological malignancies. *Pediatric Dentistry*; **11**(4): 303-306.

De Salvia A, Calzetta C, Orrico M and De Leo D (2004). Third mandibular molar radiological development as an indicator of chronological age in a European population. *Forensic Science International;* **146** (suppl):S9-S12.

Dhanjal KS, Bhardwaj MK and Liversidge HM (2006). Reproducibilty of radiographic stage assessment of third molars. *Forensic Science International;* **1595**: S74-S77.

Directgov; the website of the UK government. http://www.direct.gov.uk/en/Parents/CrimeAnd YoungOffenders/DG_4003033. Accessed November 2009.

Demirjian A and Goldstein H (1976). New systems for dental maturity based on the seven and four teeth. *Annals of Human Biology;* **3**(5): 411-21.

Demirjian A, Goldstein H and Tanner JM (1973). A new system of dental age assessment, *Human Biology*; **45**: 221-227.

Demirjian A and Levesque GY (1979). Sexual differences in dental development and prediction of emergence. *Journal of Dental Research;* **59**: 1110-1122.

Derluyn I and Broekaert E (2007). Different perspectives on emotional and behavioural problems in unaccompanied refugee children and adolescents. *Ethnicity & Health;* **12**(2):141-162.

E

Eid RMR, Simi R, Friggi MNP and Fisberg M (2002). Assessment of dental maturity of Brazilian children aged 6 to 14 years using Demirjian's method. *International Journal of Paediatric Dentistry;* **12**: 423-428.

Elmer E (1977). A follow-up study of traumatized children. *Pediatrics;* **59**: 273-279.

F

Food and Nutrition Research Institute, Phillipines (2003). Part II: Anthropometric facts and figures. http://www.fnri.dost.gov.ph/files/fnri%20files/nns/factsandfigures2003/anthropometric.pdf. Accessed May 2008.

Frucht S, Schnegelsberg C, Schulte-Mönting J, Rose E and Jonas I (2006). Dental age in southwest Germany. A radiographic study. *Journal of Orofacial Orthopedics;* **61**(5):318-29.

G

Garn SM, Lewis AB and Polacheck DL (1959). Variability of tooth formation. *Journal of Dental Research;* **38**: 135-147.

Garn SM, AB and Bonne B (1962). Third molar polymorphism and the timing of tooth formation. *Nature;* **192**: 989.

Garn SM, Lewis AB and Blizzard RM (1965a). Endocrine factors in dental development. *Journal of Dental Research;* **44**: 243-258.

Garn SM, Lewis AB and Kerewsky RS (1965b). Genetic, nutritional and maturational correlates of dental development. *Journal of Dental Research;* **44**: 228-242.

Garn SM, Wertheimer F, Sandusky ST and McCann MB (1972). Advanced tooth emergence in negro individuals. *Journal of Dental Research;* **51**: 1506.

Gat H, Sarnat H, Bjotvatn K and Dayan D (1984). Dental age evaluation: a new six developmental stage method. *Clinical Preventive Dentistry;* **6**: 18-21.

Guatelli-Steinberg D, Sciulli PW, Betsinger TK (2008). Dental crown size and sex hormone concentrations: another look at the development of sexual dimorphism. *American Journal of Physical Anthropolology;* **137**(3): 324-333.

Gillett RM (1997). Dental emergence among urban Zambian school children: an assessment of the accuracy of three methods of assigning age. *American Journal of Physical Anthropology;* **102**: 447-454.

Gleiser I and Hunt EE (1955). The permanent mandibular first molar: its calcification, eruption and decay. *American Journal of Physical Anthropology;* **13**(2); 253-283.

Gravely JF (1965). A radiographic survey of third molar development. *British Dental Journal;* **119**(9): 397-401.

Green LJ (1961). The interrelationships among height, weight and chronological, dental and skeletal ages. *The Angle Orthodontist;* **31**(3): 189-193.

Greulich WW and Pyle SI (1959). *Radiographic atlas of skeletal development of hand and wrist*, 2nd edition, California, Stanford University Press.

Greulich WW, Pyle SI and Waterhouse AM (1971). *A radiographic standard of reference for the growing hand and wrist.* Chicago, Case Western Reserve University.

Grine FE, Stevens NJ, Jungers WL (2001). An evaluation of dental radiograph accuracy in the measurement of enamel thickness. *Archives of Oral Biology;* **46**(12): 1117-1125.

Gunst K, Mesotten K, Carbonez A and Willems G (2003). Third molar root development in relation to chronological age: a large sample sized retrospective study. *Forensic Science International;* **136**: 52-57.

Gustafson G and Koch G (1974). Age estimation up to 16 years of age based on dental development. *Proceedings of the Finnish Dental Society*; **25**: 297-306.

H

Haavikko K (1970). The formation and the alveolar and clinical eruption of the permanent teeth; An orthopantomographic study. *Suomen Hammaslaakariseuran Toimituksia;* **66**: 104-170.

Haavikko K (1974). Tooth formation age estimated on a few selected teeth. A simple method for clinical use. *Proceedings of the Finnish Dental Society;* **70**(1): 15-19.

Hagg U and Matsson L (1985). Dental maturity as an indicator of chronological age: the accuracy and precision of three methods. *European Journal of Orthodontics;* **7**(1):25-34.

Hagg U and Taranger J (1986). Timing of tooth emergence. A prospective longitudinal study of Swedish urban children from birth to 18 years. *Swedish Dental Journal;* **10**: 195-206. *European Journal of Orthodontics;* **7**: 25-34.

Home office; research development statistics (2008). http://rds.homeoffice.gov.uk /rds/pdfs08/hosb1108.pdf. Accessed April 2008.

Horner L (1834). *The Factories Regulation Act explained with some remarks on its origin, nature and tendency*, Glasgow, Hedderwick.

Hotz R, Boulanger G and Weisshaupt H (1959). Calcification time of permanent teeth in relation to chronological and skeletal age in children. *Helvetica Odontologica Acta;* **3**: 4-9.

J

Jaffe EC, Roberts GJ, Chantler C and Carter JE (1990). Dental maturity in children with chronic renal failure assessed from dental panoramic tomogrpahs. *Journal of the International Association of Dentistry for Children*; **20**(2):54-58.

Johanson G (1971). Age determination from human teeth. *Odontologisk Revy;* **22**(suppl): 6-39.

K

Kataja M, Nyström M and Aine L (1989). Dental maturity standards in southern Finland. *Proceedings of the Finnish Dental Society;* **85**(3):187-197.

Keller EE, Sather AH and Hayles AB (1970). Dental and skeletal development. I various endocrine and metabolic diseases. *Journal of the American Dental Association;* **81**: 415-419.

Koshy S and Tandon S (1998). Dental age assessment: the applicability of Demirjian's method in South Indian children. *Forensic Science International;* **94**: 73-85.

Kreitner KF, Schweden FJ, Riepert T, Nafe B and Thelen M (1998). Bone age determination based on the study of the medial extremity of the clavicle. *European Radiology;* 8: 1116-1122.

Kullman L (1995). Accuracy of two dental and one skeletal age estimation method in Swedish adolescents. *Forensic Science International;* **75**(2-3):225-236.

Kullman L, Johanson G and Akesson L (1992). Root development of the third molar and its relation to chronological age. *Swedish Dental Journal;* **16**: 161-167.

Kvaal S, Kollveit K, Thomsen I and Solheim T (1995). Age estimation of adults from dental radiographs. *Forensic Science International;* **74**: 175-185.

L

Landis JR and Koch GG (1977). An application of hierarchical kappa-type statistics in the assessment of majority agreement among multiple observers. *Biometrics;* **33**(2):363-374.

Lee SE, Lee SH, Lee JY, Park HK and Kim YK (2008). Age estimation of Korean children based on dental maturity. *Forensic Science International;* **178**(2-3):125-131.

Leurs IH, Wattel E, Aartman IH, Etty E and Prahl-Andersen B (2005). Dental age in Dutch children. *European Journal of Orthodontics;* **27**(3):309-14.
Lewis AB and Garn SM (1960). The relationship between tooth formation and other maturational factors. *The Angle Orthodontist;* **30**: 70-77.

Levesque GY, Demirijian A and Tanguay R (1981). Sexual dimorphism in the development, emergence, and agenesis of the mandibular third molar. *Journal of Dental Research;* **60**(10): 1735-1741.

Liliequist B and Lundberg M (1971). Skeletal and tooth development. A methodologic investigation. *Acta Radiologica Diagnosis (Stockholm);* **11**(2): 97-112.

Liversidge HM, Speechly T and Hector MP (1999). Dental maturation in British children: are Demirjian's standards applicable? *International Journal of Paediatric Dentistry;* **9**(4):263-269.

Liversidge HM, Lyons F and Hector MP (2003). The accuracy of three methods of age estimation using radiographic measurements of developing teeth. *Forensic Science International;* **131** (1): 22-29.

Liversidge HM, Chaillet N, Mörnstad H, Nyström M, Rowlings K, Taylor J and Willems G (2006). Timing of Demirjian's tooth formation stages. *Annals of Human Biology;* **33**(4):454-470.

Liversidge HM (2008a). *Dental Age revisited, in Technique and application in Dental Anthroplogy*, eds: Irish JD and Nelson GC, pp 243-252, Cambridge, Cambridge Press.

Liversidge HM (2008b). Timing of human mandibular third molar formation. *Annals of Human Biology;* **35**(3):294-321.

Loevy HT and Goldberg AF (1999). Shifts in tooth maturation patterns in non-French Canadian boys. *International Journal of Paediatric Dentistry;* **9**: 105-110.

Logan WHG and Kronfield R (1933). Development of the human jaws and surrounding structures from birth to the age of fifteen years. *The Journal of the American Dental Association*; **20**(3): 379-427.

M

McKenna CJ, James H, Taylor JA and Townsend GC (2002). Tooth development standards for South Australia. *Australian Dental Journal;* **47**(3):223-227.

Maber M, Liversidge HM and Hector MP (2006). Accuracy of age determination of radiographic methods using developing teeth. *Forensic Science International;* **159**(suppl 1): S68-S73.

Martin-de las HS, Garcia-Fortea P, Ortega A, Zodocovich S and Valenzuela A (2008). Third molar development according to chronological age population from Spanish and Magrebian origin. *Forensic Science International;* **174**: 47-53.

Meijerman L, Maat GJ, Schulz R and Schmeling A (2007). Variables affecting the probability of complete fusion of the medial clavicular epiphysis. *International Journal of Legal Medicine;* **121**(6): 463-468.

Meinl A, Tangl S, Huber C, Maurer B and Watzek G (2007). The chronology of third molar mineralization in the Austrian population - a contribution to forensic age estimation. *Forensic Science International;* **169**(2-3):161-167.

Melsen B, Wenzel A, Miletic T, Andreasen J, Vagn-Hansen P and Terp S (1986). Dental and skeletal maturity in adoptive children; assessments at arrival and after one year in the admitting country. *Annals of Human Biology;* **13**: 153-159.

Mesotten K, Gunst K, Carbonez A and Willems G (2003). Chronological age determination based on the root development of a single third molar: a retrospective study based on 2513 OPGs. *Journal of Forensic Odonto-Stomatology;* **21**(2):31-35.

Mincer HH, Harris EF and Berryman HE (1993). The AFBO study of thirs molar development and its use as an estimator of chronological age. *Journal of Forensic Science;* **38**: 379-390.

Mitchell JC, Roberts GJ, Donaldson AN and Lucas VS (2009). Dental age assessment (DAA): reference data for British Caucasian at the 16 year threshold. *Forensic Science International;* 189: 19-23.

Mora S, Boechat MI, Pietka E, Huang HK and Gilsanz V (2001). Skeletal age determinations in children of European and African descent: applicability of the Greulich and Pyle standards. *Pediatric Research;* **50**(5):624-628.

Moorrees CFA, Fanning EA and Hunt EE (1963). Age variation of formation stages for ten permanent teeth. *Journal of Dental Research;* **42**: 1490-1502.

Mörnstad H, Reventlid M and Tievens A (1995). The validity of four methods of age determination by teeth in Swedish children: a multicentre study. *Swedish Dental Journal;* **19**: 121-130.

Mörnstad H, Staaf V and Welander U (1994). Age estimation with the aid of tooth development: a new method based on objective measurements. *Scandinavian Journal of Dental Research;* **102**: 137-143.

Morse DR (1991). Age-related changes of the dental pulp complex and their relationship to systemic aging. *Oral Surgery, Oral Medicine, Oral Pathology;* **72**(6): 721-745.

Moze K (2009). *Dental Age Assessment (DAA) in Trinidad and Tobago: setting standards and developing an AfroTrinidian Reference Data Set (RDS).* MSc degree in Dental and MaxilloFacial Radiology. University of London.External Program.

Mugonzibwa EA, Kuijpers-Jagman AM, Laine-Alava MT and van't Hof MA (2002). Emergence of the permanent teeth in Tanzanian children. *Community Dentistry and Oral Epidemiology;* **30**: 455-462.

Myers RE (2009). Child Development Institute, http://www.childdevelopmentinfo.com/development/piaget.shtml. Accessed June 2008.

N

Nanda RS and Chawla TN (1966). Growth and development of the dentitions in Indian children; I Development of permanent teeth. *American Journal of Orthodontics;* **52**(11): 837-853.

Nolla CM (1960). The development of the permanent teeth. *Journal of Dentistry in Children;* **27**: 254-266.

Nortjé CJ (1983). The permanent third molar. It's value in age determination. *Journal of Forensic Odonto-Stomatology;* **1**: 27-31.

Nystrom M, Kleemola-Kujala E, Evalahti M and Peck L (2001). Emergence of the permanent teeth and dental age in a series of Finns. *Acta Odontologica Scandinavica;* **59**: 49-56.

Nykanen R, Espeland I, Kvaal S and Krogstad O (1998). Validity of the Demirjian method for dental age estimation when applied to Norwegian children. *Acta Odontologica Scandinavica;* **56**: 238-244.

O

Office of National Statistics (2002). Social focus in brief: ethnicity. http://www.statistics.gov.uk/downloads/theme_social/social_focus_in_brief/ethnicity/ethnicity.pdf Accessed August 2005.

Office of National Statistics (2004). Ethnicity and identity. http://www.statistics.gov.uk/cci/nugget.asp?id=457. Accessed August 2005.

Office of National Statistics. National Census 2001. http://www.statistics.gov.uk/census2001/access_results.asp. Accessed December 2004.

Olze A, Taniguchi M, Schmeling A, Zhu BL, Yamada Y, Maeda H and Geserick G (2003). Comparative study on the chronology of third molar mineralization in a Japanese and a German population. *Legal Medicine (Tokyo);* **5** Suppl 1:S256-60.

Olze A, Schmeling A, Taniguchi M, Van Niekerk P, Wernecke KD and Geserick G (2004). Forensic age estimation in living subjects: the ethnic factor in wisdom teeth mineralization. *International Journal of Legal Medicine;* **118**(3):170-173.

Olze A, Bilang D, Schmidt S, Wernecke KD, Geserick G and Schmeling A (2005a). Validation of common classification systems for assessing mineralization of thirs molars. *International Journal of Legal Medicine;* **119**: 22-26.

Olze A, Mahlow A, Schmidt S, Wernecke K, Geserick G and Schmeling A (2005b). combined determination of selected radiological and morphological variables relevant for dental age estimation of young adults. *Homo - Journal of Comparative Human Biology;* **56**: 133-140.

Olze A, van Nierkerk P, Ishikawa T, Zhu BL, Sculz, Maeda H and Schmeling A (2006). Studies on the progress of third-molar mineralization in a Black African population. *Homo - Journal of Comparative Human Biology;* **57**: 209-217.

Orhan K, Ozer L, Dogan S and Paksoy CS (2006). Radiographic evaluation of thirs molar development in relation to chronological age among Turkish children and youth. *Forensic Science International;* **165**(1): 46-51.

Osborn JW (1981). *Dental anatomy and embryology. A companion to dental studies, volume 1, book 2,* 1st edition, Oxford, Blackwell.

Otuyemi OD, Ugboko VI, Ndukwe KC and Adeykoya-Sofowora CA (1997). Eruption times of third molars in young rural Nigerians. *International Dental Journal;* **47**: 266-270.

P

Paewinsky E, Pfeiffer H and Brinkmann B (2005). Quantification of secondary dentine formation from orthopantomograms - a contribution to forensic age estimation methods in adults. *International Journal of Legal Medicine;* **119**(1): 27-30.

Peiris TS, Roberts GJ and Prabhu N (2009). Dental age assessment: a comparison of 4 to 24-year olds in the United Kingdom and an Australian population. *International Journal of Paediatric Dentistry:* 19: 367-376.

Pelsmaekers B, Loos R, Carels C, Derom C and Vlietinck R (1997). The genetic contribution to dental maturation. *Journal of Dental Research;* **76**(7): 1337-1340.

Prieto JL, Barbería E, Ortega R and Magaña C (2005). Evaluation of chronological age based on third molar development in the Spanish population. *International Journal of Legal Medicine;* **119**(6):349-354.

Psoter WJ, Morse DE, Pendrys DG, Zhang H and Mayne ST (2003). Median ages of eruption of the primary teeth in White and Hispanic children from Arizona. *Pediatric Dentistry;* **25**: 257-261.

Physicians for Human Rights. From persecution to prison: the health consequences of detention for asylum seekers (2003). http://physiciansforhumanrights.org /library/documents/reports/report-perstoprison-2003.pdf. Accessed December 2006.

Q

QuimbachF, Ramsthaler F and Verhoff MA (2009). Evaluation of the ossification of the medial clavicular epiphysis with a digital ultrasonic system to determine the age threshold of 21 years. *International Journal of Legal Medicine;* **123**: 241-245.

R

Ramsthaler F, Proschek P, Betz W and Verhoff MA (2009). How reliable are the risk estimates for X-ray examinations in forensic age estimations? A safety update. *International Journal of Legal Medicine;* **123**(3): 199-204.

Reid DJ and Dean MC (2006). Variation in modern human enamel formation times. *Journal of Human Evolution;* **50**: 329-346.

Roberts GJ, Parekh S, Petrie A and Lucas VS (2008). Dental age assessment (DAA): a simple method for children and emerging adults. *British Dental Journal;* **204**(4):E7.

Rosen AA and Baumwell J (1981). Chronological development of the dentition of medically indigent children: a new perspective. *ASDC Journal of Dentistry in Children;* **48**(6): 437-442.

Royal College of Paediatrics and Child Health (2007). http://www.rcpch.ac.uk/Policy /Policy-Statements Accessed June 2008.

S

Sapoka AA and Demirjian A (1971). Dental development of the French Canadian child. *Journal of the Canadian Dental Association;* **37**(3):100-104.

Sarnat H, KaffeI, Porat J and Amir E (2003). Developmental stages of the third molar in Israeli children. *Pediatric Dentistry;* **25**: 373-377.

Saunders E (1837). *The teeth, a test of age, considered with reference to the factory children: Addressed to both Houses of Parliament*, London, Renshaw.

Saxena S, Ambler G, Cole TJ and Majeed A (2004). Ethnic group differences in overweight and obese children and young people in England: cross sectional survey. *Archives of Disease in Childhood;* **89**: 30-36.

Schour I and Massler M (1941). The development of the human dentition. *Journal of the American Dental Association;* **28**: 1153-1160.

Schmeling A, Olze A, Reisinger W and Geserick G (2001). Age estimation of living people undergoing criminal proceedings. *Lancet;* **358**(9276): 89-90.

Schmeling A, Olze A, Reisinger W, Rösing FW and Geserick G (2003). Forensic age diagnostics of living individuals in criminal proceedings. *Homo - Journal of Comparative Human Biology*; **54**(2):162-169.

Schmeling A, Schulz R, Reisinger W, Muuhler M, Wernecke KD and Geserick G (2004). Studies of the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography. *International Journal of Legal Medicine;* **118**: 5-8.

Schmeling A, Reisinger W, Geserick G and Olze A (2006), Age estimation of unaccompanied minors. Part I. General considerations. *Forensic Science International;* **159** (suppl 1): S61-4.

Schulz R, Mühler M, Mutze S, Schmidt S, Reisinger W and Schmeling A (2005). Studies of the time frame for ossifcation of the medial epiphysis of the clavicle as revealed by CT scans. *International Journal of Legal Medicine;* **119**: 142-145.

Schulz R, Mühler M, Reisinger W, Schmidt S and Schmeling A (2008a). Radiographic staging of ossification of the medial clavicular epiphysis. *International Journal of Legal Medicine;* **122**: 55-58.

Schulz R, Zwiesigk P, Schiborr M, Schmidt S and Schmeling A (2008b). Ultrasound studies on the time course of clavicular ossification. *International Journal of Legal Medicine;* **122**: 163-167.

Schulze D, Rother U, Fuhrmann A, Richel S, Faulmann G and Heiland M (2006). Correlation of age and ossification of the medial clavicular spiphysis using computed tomography. *Forensic Science International;* **158**: 184-189.

Scottish Government. Scotland's New Ethnicity Classification for Scottish Official Statistics and Recommended for Scotland's 2011 Census. http://www.scotland.gov.uk/Publications/2008/07/29095058/7. Accessed December 2009.

Senior PA and Bhopal R (1994). Ethnicity as a variable in epidemiological research. *British Medical Journal*; **309** (6950):327-330.

Sisman Y, Uysal T, Yagmur Fand Ramoglu SI (2008). Third-molar development in relation to chronologic age in Turkish children and young adults. The *Angle Orthodontist;* **77**(6):1040-1045.

Solari AC and Abramovitch K (2002). The accuracy and precision of third molar development as an indicator of chronological age in Hispanics. *Journal of Forensic Science;* **47**: 531-535.

Soo-Hyun L, Jeong-Yun L, Hee-Kyung P and Young-Ku K (2009). Development of third molars in Korean juveniles and adolescents. *Forensic Science International;* **188**: 107-111.

Staaf V, Mörnstad H and Welander U (1991). Age estimation based on tooth development; a test of reliability and validity. *Scandinavian Journal of Dental Research;* **99**: 281-286.

Statline CBS: The state of health of the Dutch population (1991-200). http://statline.cbs.nl/StatWeb/publication/?DM=SLEN&PA=7068eng. Accessed June 2008.

Stern CMM (2008). *Age assessment in young people: witness statement to the courts,* Report.

Sun SS, Schubert CM, Chumlea WC, Roche AF, Kulin HE, Lee PA, Himes JH, Ryan AS. (2002). National estimates of the timing of sexual maturation and racial differences among US children. *Pediatrics;* **110**: 911-919.

Supreme Court. http://www.supremecourt.gov.uk/docs/uksc 2009 0106 judgment.pdf Accessed August 2009.

Svanholt M and Kjaer I (2008). Developmental stages of permanent canines, premolars, and 2nd molars in 244 Danish children. *Acta Odontologica Scandinavica;* **66**(6):342-350.

T

Tanner JM (1962). *Growth and adolescence*, 2nd edition, Oxford, Blackwell.

Tanner JM, Whitehouse RH, Cameron N, Marshall WA, Healy MJR and Goldstein H (1983). *Assessment of skeletal maturity an prediction of adult height*, 2nd edition, London, Academic Press.

Tanner JM, Whitehouse RH, Marshall WA, Healy MJR and Goldstein H (1975). *Assessment of skeletal maturity and prediction of adult height: TW2 method.* Academic Press, New York.

Taylor JR (1997). *An introduction to error analysis: the study of uncertainties in physical measurements*, 2nd edition, California, University Science Books.

Teivens A and Mörnstad H (2001). A modification of the Demirjian method for age estimation in children. *Journal of Forensic Odonto-Stomatology;* **19**(2):26-30.

Teivens A, Monro P and Reventlid M (1996). Individual variation of tooth development in Swedish children. *Swedish Dental Journal;* **20**: 87-93.

Thomson A (1936). Lectures on Medical Jurisprudence. Lecture 7 – “Age”. *Lancet;* **1**: 281-286.

Thorson J and Hagg U (1991). The accuracy and precision of the third molar as an indicator of chronological age. *Swedish Dental Journal;* **15**: 15-22.

Tokuoka O (1989). The principles of panoramic tomography. *Oral Radiology;* **5**(1): 31-38.

Tonge CH and McCance RA (1973). Normal development of the jaws and teeth in pigs, and the delay produced by calorific deficiencies. *Journal of Anatomy;* **115**: 1-22.

Tunc ES and Koyuturk AE (2008). Dental age assessment using Demirjian's method on northern Turkish children. *Forensic Science International;* **175**(1):23-26.

U

UNICEF. Child info: Monitoring the situation of women and children. http://www.childinfo.org/birth_registration_challenge.html Accessed November 2009.

US Food and Drug Administration. Reducing radiation from Medical x rays. http://www.fda.gov/ForConsumers/ConsumerUpdates/ucm095505.htm. Accessed February 2010.

University of Nottingham, School of Nursing Educational Technology Group. http://www.nottingham.ac.uk/nmp/sonet/rlos/ebp/confidence_intervals/index.html?f_title=Confidence+intervals&submit2=Go+to+RLO. Accessed October 2009.

W

Willems G, Van Olman L, Spiessens B and and Carels C (2001). Dental age estimation in Belgian children: Demirjian's technique revisited. *Journal of Forensic Science*; **46**(4): 893-895.

Willerhausen B, Loffler N and Schulze R (2001). Analysis of 1202 orthopantograms to evaluate the potential of forensic age determination based on third molar development stages. *European Journal of Medical Research;* **6**: 377-384.

World health Organization. Physical status: the use and interpretation of anthropometry. Report of a WHO Expert Committee. Technical Report Series No. 854 http://whqlibdoc.who.int/trs/WHO_TRS_854.pdf. Accessed November 2009.

Appendix 1 - Ethnic group classification for England and Wales based on the 2001 National Census

Level 1	**Level 2**
WHITE	WHITE
	British
	Irish
	Other White background
	All White groups
MIXED	MIXED
	White and Black Caribbean
	White and Black African
	White and Asian
	Other Mixed background
	All Mixed groups
ASIAN or ASIAN BRITISH	ASIAN or ASIAN BRITISH
	Indian
	Pakistani
	Bangladeshi
	Other Asian background
	All Asian groups
BLACK or BLACK BRITISH	BLACK or BLACK BRITISH
	Caribbean
	African
	Other Black background
	All Black groups
CHINESE or OTHER ETHNIC GROUP	CHINESE or OTHER ETHNIC GROUP
	Chinese
	Other ethnic group
	All Chinese or Other groups
ALL ETHNIC GROUPS	
NOT STATED	

Appendix 2 – Information sheet for parents

Patient Information Sheet

Dental Age Assessment

1. Study Title:

Dental Age Assessment. The estimation of the age of infants, children and young persons from dental radiographs.

2. Invitation:

We are asking for your help with a research study. Before you decide it is important to understand why the research is being done and what it will involve. Please take time to read the following information carefully and discuss it with others if you wish. Ask us if there is anything that is not clear or if you would like more information.

Take time to decide whether or not you wish to take part.

3. What is the purpose of the study?

From time to time dental specialists are asked to assist lawyers e.g. solicitors, barristers and judges by providing an estimate of the age of an infant, child or young person based on a clinical and radiographic (xray) examination of the teeth. The methods that we have available at present make the estimates unreliable.

To improve the methods of estimation we need to examine several thousand xrays of young people like you for whom we have a known date of birth. This will enable us to provide standards for use in the United Kingdom. Once we have sufficient numbers of xrays it will be possible to use statistical methods to improve the reliability of our estimates.

4. Why have I been chosen?

We are looking for xrays which show clear images of all the teeth. If your xray provides a very clear picture we would like to use it for the study.

5. What is involved in the study?

If your xray is of good quality it would be helpful to have some additional information. First we need to take details of your health. This is to ensure that we take full account of any medical problems that might affect growth. Second we need to ask you to describe your ethnic or genetic background. This is to ensure that growth differences between ethnic and racial groups can be properly considered when setting and publishing the growth standards.

It is important for you to be aware that we are not taking these xrays just for the study. We will be re-using xrays already in existence which have been used by your dentist to help with your treatment. This means there are no risks to you associated with the study.

6. The information about the research subject.

The information we collect will be he held on a secure computer. This will have the following information: hospital identity number, first name, surname, date of birth, date of xray, health details, and your description of your own ethnicity or racial background and a copy of the xray(s).

All the information which is collected about you during the course of the research will be kept strictly secret. Any information about you which leaves the hospital will have not have details by which you could be recognised. Name, address, date of birth, and all identifiable information including hospital identification number will be removed so that you cannot be recognised by it. The database that has been set up exports the data as columns of figures that cannot be related to your personal details. The delinking of the personal details from the data in the database will take place on a daily or weekly basis as the computer updates its output to add new data.

The Data Controllers are Professor Graham Roberts (Paediatric Dentist) and Miss Susan Parekh (PhD Research Scholar). The confidentiality of subjects on the data base is maintained with a secret password. The Responsibility for maintaining security and controlling access to the data will be shared between Graham Roberts, Victoria Lucas, and Susan Parekh.

7. What will happen when the research stops?

The data we obtain will be used mostly for forensic purposes to assist lawyers and police in estimating the age of human beings from the dentition. The main database with personal details will continue to exist in the form of three copies. One copy will be in a locked cupboard in a locked office here at the Eastman. The second copy will be in a locked fireproof safe at my home, and the third copy on a passworded laptop computer under my direct care. It is important to keep these master copies because if there are legal proceedings we may be subjected to detailed cross examination and we must be able to demonstrate to the judge that the information we have is of assured provenance.

8. What will happen if the findings may affect you personally?

If we discover any information that may affect you personally we will make arrangements to contact you so that you can make a decision about whether or not you want further advice.

9. What if something goes wrong?

The only things that could go wrong are related to the acquisition and analysis of the data by computer. This will not affect you at all.

10. What will happen with the results of the study?

The summary and interpretation of the results will be published in scientific journals. You will not be identified in any of these articles.

11. Who is organising and funding the Research?

There is no external research funding at present. In due course we will be applying to charities and research councils for financial assistance. The research is being organised in the Unit of Paediatric Dentistry and / or The School of Dental Therapy at The Eastman Dental Institute and Hospital.

If you have any complaints about the project you should first contact one of the research workers to see if your concerns can be dealt with promptly. Alternatively you are entitled to use the complaints procedure of University College Hospital.

12. Withdrawal from the project

Your participation is entirely voluntary. As it does not involve any additional activity on your part the consent you give is for us to use part of your clinical records for legitimate research purposes.

If at any time you wish to withdraw your consent you may do so. You should contact one of the people below who will arrange for the information to be removed from the computer database.

13. Who has reviewed the study?

The study has been reviewed by the National Hospital for Neurosurgery and Neurology and the Institute of Neurology Joint Research Ethics Committee.

14. Documentation

You will be provided with a copy of this information and a duplicate of the signed consent form.

The Eastman Dental Hospital and Institute Department of Paediatric Dentistry 256 Gray's Inn Road London WC1X 8LD	Miss Susan Parekh Tel 020 7915 2319 Email **s.parekh@eastman.ucl.ac.uk** Professor Graham Roberts tel 020 7915 1167 email **g.roberts@eastman.ucl.ac.uk**

Please contact Miss Susan Parekh (020 7915 2319) or Professor Graham Roberts (020 7915 1167) if you have any questions or concerns about the project.

Appendix 3 – Consent form for parents

Centre Number: Eastman Dental Hospital UCLH

Project ID number: 03/E023

Patient Identification Number for this study: Form version 2

date:

PARENTAL / CARER CONSENT FORM

Title of project: **Dental Age Assessment**

Name of Principal investigators: Miss Susan Parekh / Professor Graham J Roberts

Please initial box

1. I confirm that I have read and understood the information sheet dated 16 March 2004 (version 2 -two.) for the above study and have had the opportunity to ask questions. ☐

2. I confirm that I have had sufficient time to consider whether or not want to be included in the study ☐

3. I understand that my daughter's/son's participation is voluntary and that I am free to withdraw at any time, without giving any reason, without my medical care or legal rights being affected. ☐

4. I understand that sections of any of my daughter's/sons medical notes may be looked at by responsible individuals from (The Eastman Dental Hospital) or from regulatory authorities where it is relevant to my taking part in research. I give permission for these individuals to have access to my records. ☐

5. I agree to allow my daughter's/son's radiographs to be used for this study. ☐

Title of project: Dental Age Assessment

Name of Principal investigators: Miss Susan Parekh / Professor Graham Roberts

________________	__________________	___________
Name of patient	Date	Signature
______________________	______________________	___________
Name of Person taking consent	Date	Signature

Susan Parekh	s.parekh@eastman.ucl.ac.uk / 020 7915 2319
Researcher (to be contacted if there are any problems)	Email/phone number

Comments or concerns during the study

> If you have any comments or concerns you may discuss these with the investigator. If you wish to go further and complain about any aspect of the way you have been approached or treated during the course of the study, you should write or get in touch with the Complaints Manager, UCL hospitals. Please quote the UCLH project number at the top this consent form.

1 form for Patient;

1 to be kept as part of the study documentation,

1 to be kept with hospital notes

Appendix 4 – Consent form for parents (version 2)

Centre Number: Eastman Dental Hospital
Patient Identification Number for this study:

UCLH Project ID number: 03/E02
Form version 3

PARENTAL / CARER CONSENT FORM

Title of project: **Dental Age Assessment**
Name of Principal Investigators: Professor Graham J. Roberts / Miss Susan Parekh

Please initial or tick box

1. I confirm that I have read and understood the information sheet dated 16th March 2004 (version 2-two.) for the above study and have had the opportunity to ask questions. ☐
2. I confirm that I have had sufficient time to consider whether or not I want my daughter / son to be included in the study. ☐
3. I understand that my daughter's / son's participation is voluntary and that I am free to withdraw her / him at any time, without giving any reason, without her / his medical care or legal rights being affected. ☐
4. I understand that sections of any of my daughter's / son's medical notes may be looked at by responsible individuals from The Eastman Dental Hospital or from regulatory authorities where it is relevant to her / his taking part in research. I give permission for these individuals to have access to her / his records. ☐
5. I agree to allow my daughter's / son's radiographs to be used for this study. ☐

Name of patient	**Date**	**Signature**
Name of person taking consent	Date	Signature

Professor Graham Roberts g.roberts@eastman.ucl.ac.uk / 020 7915 1167
Susan Parekh s.parekh@eastman.ucl.ac.uk / 020 7915 2319
Researchers (to be contacted if there are any problems) e-mail telephone number

Top copy to be kept as part of the study documentation
1 copy for the Patient
1 copy to be kept with the hospital notes

Comments or concerns during the study
If you have any comments or concerns you may discuss these with the investigator. If you wish to go further and complain about any aspect of the way you have been approached or treated during the course of the study, you should write or get in touch with the Complaints Manager, UCL Hospitals. Please quote the UCLH project number: 03/E02.

University College London Hospitals NHS
NHS Foundation Trust

Patient Sticker or Hospital ID Number

Dental / Medical condition:

Date x-ray taken: ______________

ETHNICITY *Please initial or tick box*

WHITE ☐ **or**

WHITE
- British ☐
- Irish ☐
- Other White background ☐
- All White groups ☐

MIXED
- White and Black Caribbean ☐
- White and Black African ☐
- White and Asian ☐
- Other Mixed background ☐
- All Mixed groups ☐

ASIAN or ASIAN BRITISH
- Indian ☐
- Pakistani ☐
- Bangladeshi ☐
- Other Asian background ☐
- All Asian groups ☐

BLACK or BLACK BRITISH
- Caribbean ☐
- African ☐
- Other Black background ☐
- All Black groups ☐

CHINESE or OTHER ETHNIC GROUP
- Chinese ☐
- Other ethnic group ☐
- All Chinese or Other groups ☐

OTHER ETHNIC GROUPS ☐

NOT STATED ☐

Please complete:
Patient's country of birth:
Mother's country of birth:
Father's country of birth:

Appendix 5 – Mornstad measurements for subject Y

LL1_ch	**LL1_aw**	**LL1_y**	**LL1_x**	**LL1_rl**	**LL2_ch**	**LL2_aw**	**LL2_y**	**LL2_x**	**LL2_rl**
6	3.2	10.3	9.9	10.1	7.1	4.4	6.9	6.6	6.75
LL3_ch	**LL3_aw**	**LL3_y**	**LL3_x**	**LL3_rl**	**LL4_ch**	**LL4_aw**	**LL4_y**	**LL4_x**	**LL4_rl**
8.7	6.2	5.3	4.6	4.95	7.8	5.3	2.3	2.1	2.2
LL5_ch	**LL5_x**	**LL5_y**	**LL5_rl**	**LL5_aw**	**LL6_ch**	**LL6_mrl**	**LL6_drl**	**LL6_arl**	**LL6_maw**
8.2	0.8	0.7	0.75	6.2	9.4	7.7	4.9	6.3	2
LL6_daw	**LL6_aaw**	**LL7_ch**	**LL7_mrl**	**LL7_drl**	**LL7_arl**	**LL7_maw**	**LL7_daw**	**LL7_aaw**	
3.2	2.6	9.7	2	1.4	1.7	0.2	0.6	0.4	

Appendix 6 – Results for the 50 DPT's used for comparison of the methods

ID no	G	CA	DA Mörnstad	DA-CA Mörnstad	Demirjian maturity score	DA Demirjian	DA-CA Demirjian	DA Haavikko	DA-CA Haavikko	DA weighted average	DA-CA weighted average
1	F	11.3	12.9	-1.58	962	11.5	-0.2	10.01	1.29	11.29	0.0
2	F	8.8	7.2	1.58	907	9.9	-1.1	9.23	-0.42	9.99	-1.2
3	M	9.5	10.5	-1.04	969	12.6	-3.1	10.98	-1.48	12.11	-2.6
4	F	7.4	8.7	-1.25	694	7.4	0.0	7.25	0.15	7.86	-0.5
5	F	14.4						11.74	2.66	16.45	-2.1
6	F	6.2	9.9	-3.67	459	6.4	-0.2	5.59	0.61	5.9	0.3
7	M	5.0	11.3	-6.30				5.07	-0.07	5.13	-0.1
8	F	12.5	7.2	5.34	962	11.5	1.0	10.37	2.13	11.65	0.9
9	M	10.2	6.4	3.85	973	12.9	-2.7	11.05	-0.85	12.31	-2.1
10	M	13.6	10.4	3.23	979	13.3	0.3	11.78	1.82	12.81	0.8
11	M	7.9	7.2	0.64	733	8.1	-0.2	7.27	0.63	7.62	0.3
12	M	16.2			992	14.6	1.6	11.98	4.22	13.6	2.6
13	F	18.7									
14	F	10.1	12.8	-2.69	973	12.2	-2.1	9.97	0.13	11.92	-1.8
15	F	8.4	14.0	-5.60	694	7.4	1.0	6.99	1.41	7.74	0.7

16	F	6.9	9.3	-2.45	524	6.5	0.4	3.33	3.57	6.49	0.4
17	M	11.3	9.5	1.78	969	12.6	-1.3	10.46	0.84	11.65	-0.4
18	F	7.3	7.8	-0.52	694	7.4	-0.1	6.42	0.88	7.47	-0.2
19	F	7.7	7.5	0.17	895	9.7	-2.0	8.79	-1.09	8.97	-1.3
20	F	14.2			995	14.6	-0.4	11.07	3.13	13.51	0.7
21	M	13.8	8.2	5.59	992	14.6	-0.8	11.03	2.77	13.08	0.7
22	F	9.9	6.7	3.15	950	11	-1.1	9.50	0.40	10.36	-0.5
23	F	5.6	13.1	-7.47	417	5.8	-0.2	5.29	0.31	5.97	-0.4
24	M	9.0	9.5	-0.55	850	9.4	-0.4	9.09	-0.09	8.61	0.4
25	F	10.9	11.7	-0.76	962	11.5	-0.6	9.78	1.12	10.9	0.0
26	F	10.2	10.0	0.19	957	11.3	-1.1	10.20	0.00	11.55	-1.4
27	M	8.0	10.8	-2.82	628	7.6	0.4	7.49	0.51	7.31	0.7
28	F	7.0	10.5	-3.51	732	7.7	-0.7	6.99	0.01	7.71	-0.7
29	F	8.8	12.5	-3.69	794	8.6	0.2	8.36	0.44	7.98	0.8
30	F	10.7	11.5	-0.76	990	13.8	-3.1	10.92	-0.22	12.76	-2.1
31	F	14.3			995	14.6	-0.3	11.03	3.27	13.74	0.6
32	M	7.4	8.1	-0.74	788	8.6	-1.2	9.94	-2.54	7.94	-0.5
33	F	10.0	8.4	1.60	968	11.8	-1.8	10.09	-0.09	11.68	-1.7
34	F	5.9	13.3	-7.43	551	6.7	-0.8	5.23	0.67	6.75	-0.9
35	M	8.0	8.1	-0.08	799	8.7	-0.7	7.38	0.62	7.59	0.4
36	F	13.7	7.0	6.70	990	13.8	-0.1	10.82	2.88	12.81	0.9

37	M	10.8	13.4	-2.58	975	13	-2.2	10.49	0.31	12.13	-1.3
38	M	20.0									
39	F	12.8	10.5	2.26	973	12.2	0.6	10.66	2.14	12.61	0.2
40	F	11.2	11.5	-0.29	977	12.5	-1.3	10.71	0.49	12.45	-1.3
41	F	14.0	8.2	5.82	990	13.8	0.2	10.92	3.08	13.22	0.8
42	M	10.3	11.5	-1.20	906	10.5	-0.2	8.95	1.35	9.98	0.3
43	M	14.0	13.7	0.31	985	13.9	0.1	11.51	2.49	12.62	1.4
44	F	8.3	12.5	-4.21	852	9	-0.7	8.93	-0.63	8.69	-0.4
45	F	7.9	11.5	-3.58	848	8.9	-1.0	8.70	-0.80	8.71	-0.8
46	F	5.0	7.2	-2.21	523	6.5	-1.5	6.19	-1.19	6.55	-1.6
47	M	12.5	12.3	0.18	973	12.9	-0.4	11.32	1.18	12.61	-0.1
48	F	9.8	13.4	-3.57	977	12.5	-2.7	9.98	-0.18	11.07	-1.3
49	M	6.5	7.2	-0.71	352	5.3	1.2	5.17	1.33	5.55	1.0
50	M	11.0	11.0	-0.02	958	12	-1.0	10.11	0.89	10.08	0.9

Appendix 7 – SQL query for frequency tables

```
SELECT [tbl-DAA_pers_det].idno, [tbl-DAA_pers_det].recno, [tbl-DAA_pers_det].dob, [tbl-DAA_pers_det].dor, ([dor]-[dob])/365.25 AS Age, IIf([UL1-A]=-1,"A",IIf([UL1-B]=-1,"B",IIf([UL1-C]=-1,"C",IIf([UL1-D]=-1,"D",IIf([UL1-E]=-1,"E",IIf([UL1-F]=-1,"F",IIf([UL1-G]=-1,"G",IIf([UL1-H]=-1,"H")))))))) AS UL1, IIf([UL2-A]=-1,"A",IIf([UL2-B]=-1,"B",IIf([UL2-C]=-1,"C",IIf([UL2-D]=-1,"D",IIf([UL2-E]=-1,"E",IIf([UL2-F]=-1,"F",IIf([UL2-G]=-1,"G",IIf([UL2-H]=-1,"H")))))))) AS UL2, IIf([UL3-A]=-1,"A",IIf([UL3-B]=-1,"B",IIf([UL3-C]=-1,"C",IIf([UL3-D]=-1,"D",IIf([UL3-E]=-1,"E",IIf([UL3-F]=-1,"F",IIf([UL3-G]=-1,"G",IIf([UL3-H]=-1,"H")))))))) AS UL3, IIf([UL4-A]=-1,"A",IIf([UL4-B]=-1,"B",IIf([UL4-C]=-1,"C",IIf([UL4-D]=-1,"D",IIf([UL4-E]=-1,"E",IIf([UL4-F]=-1,"F",IIf([UL4-G]=-1,"G",IIf([UL4-H]=-1,"H")))))))) AS UL4, IIf([UL5-A]=-1,"A",IIf([UL5-B]=-1,"B",IIf([UL5-C]=-1,"C",IIf([UL5-D]=-1,"D",IIf([UL5-E]=-1,"E",IIf([UL5-F]=-1,"F",IIf([UL5-G]=-1,"G",IIf([UL5-H]=-1,"H")))))))) AS UL5, IIf([UL6-A]=-1,"A",IIf([UL6-B]=-1,"B",IIf([UL6-C]=-1,"C",IIf([UL6-D]=-1,"D",IIf([UL6-E]=-1,"E",IIf([UL6-F]=-1,"F",IIf([UL6-G]=-1,"G",IIf([UL6-H]=-1,"H")))))))) AS UL6, IIf([UL7-A]=-1,"A",IIf([UL7-B]=-1,"B",IIf([UL7-C]=-1,"C",IIf([UL7-D]=-1,"D",IIf([UL7-E]=-1,"E",IIf([UL7-F]=-1,"F",IIf([UL7-G]=-1,"G",IIf([UL7-H]=-1,"H")))))))) AS UL7, IIf([UL8-A]=-1,"A",IIf([UL8-B]=-1,"B",IIf([UL8-C]=-1,"C",IIf([UL8-D]=-1,"D",IIf([UL8-E]=-1,"E",IIf([UL8-F]=-1,"F",IIf([UL8-G]=-1,"G",IIf([UL8-H]=-1,"H")))))))) AS UL8, IIf([UR8-A]=-1,"A",IIf([UR8-B]=-1,"B",IIf([UR8-C]=-1,"C",IIf([UR8-D]=-1,"D",IIf([UR8-E]=-1,"E",IIf([UR8-F]=-1,"F",IIf([UR8-G]=-1,"G",IIf([UR8-H]=-1,"H")))))))) AS UR8, IIf([UL7-G]=-1 And [UL8-D]=-1,"1") AS [MATCH]
FROM [tbl-DAA_pers_det] INNER JOIN [tbl-DAA-Derm-ALL] ON [tbl-DAA_pers_det].idno = [tbl-DAA-Derm-ALL].idno
```

Appendix 8 – Summary Data Set for 12 stages (Males)

Tooth 21	Stage										
(n=1161)	o	Ci	Cco	$C_{1/2}$	$C_{3/4}$	Crc	Ri	$R_{1/4}$	$R_{1/2}$	$R_{3/4}$	Rc	Ac
n-tds	0	0	0	0	3	7	17	16	16	36	46	1020
Mean					3.70	5.00	4.94	6.16	6.54	7.94	9.03	
SD					0.30	0.99	0.68	0.85	0.93	1.12	1.26	
SE					0.17	0.37	0.17	0.21	0.23	0.19	0.19	
Median					3.70	5.18	4.78	6.02	6.60	7.83	9.00	
Minimum					3.40	3.56	3.94	4.88	5.09	4.66	6.31	
Maximum					3.99	6.38	6.25	7.98	8.35	10.91	12.87	
Range					0.59	2.82	2.32	3.10	3.26	6.25	6.56	
5%ile					3.43	3.64	3.95	5.12	5.32	6.87	7.23	
10%ile					3.46	3.71	4.11	5.28	5.46	7.10	7.66	
25%ile					3.55	4.47	4.46	5.50	5.75	7.29	8.06	
50%ile					3.70	5.18	4.78	6.02	6.60	7.83	9.00	
75%ile					3.85	5.48	5.54	6.82	7.25	8.46	9.76	
95%ile					3.96	6.13	5.91	7.31	7.82	9.88	11.09	
LCI 95%					2.96	4.09	4.59	5.70	6.05	7.56	8.65	
UCI 95%					4.43	5.92	5.29	6.61	7.04	8.32	9.40	

Tooth 22	**Stage**											
(n = 1132)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	4	9	13	16	19	29	41	38	959
Mean				4.59	4.62	5.61	5.81	6.44	7.43	8.86	9.84	
SD				1.06	0.84	1.47	1.01	0.93	0.74	1.00	1.37	
SE				0.53	0.28	0.41	0.25	0.21	0.14	0.16	0.22	
Median				4.70	4.78	5.02	5.58	6.72	7.41	8.99	9.70	
Minimum				3.40	3.56	3.81	4.46	4.66	5.44	7.05	7.69	
Maximum				5.56	5.70	8.79	8.90	8.35	8.84	11.13	13.57	
Range				2.16	2.14	4.99	4.45	3.69	3.40	4.09	5.88	
5%ile				3.49	3.62	4.05	4.50	5.05	6.09	7.30	8.01	
10%ile				3.58	3.67	4.26	4.76	5.33	6.31	7.58	8.27	
25%ile				3.84	3.94	4.62	5.45	5.64	7.19	8.21	8.79	
50%ile				4.70	4.78	5.02	5.58	6.72	7.41	8.99	9.70	
75%ile				5.45	5.18	6.70	6.19	7.04	7.84	9.46	10.79	
95%ile				5.54	5.67	7.90	7.10	7.41	8.55	10.52	11.98	
LCI 95%				2.90	3.97	4.72	5.27	5.99	7.15	8.54	9.39	
UCI 95%				6.29	5.27	6.50	6.35	6.88	7.71	9.17	10.29	

Tooth 23	**Stage**											
(n = 1170)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	3	16	12	27	57	30	55	56	914
Mean				4.05	5.20	5.30	6.43	7.80	8.81	10.40	12.21	
SD				0.72	1.02	1.11	1.04	1.13	1.01	1.39	1.47	
SE				0.42	0.25	0.32	0.20	0.15	0.18	0.19	0.20	
Median				3.70	5.19	5.11	6.70	7.83	8.78	10.28	12.29	
Minimum				3.56	3.40	3.94	3.81	4.66	7.20	7.96	9.27	
Maximum				4.88	7.31	7.98	8.94	9.76	10.97	13.57	15.90	
Range				1.32	3.91	4.04	5.13	5.11	3.76	5.61	6.63	
5%ile				3.58	3.82	4.09	5.18	5.87	7.50	8.27	9.81	
10%ile				3.59	3.97	4.24	5.45	6.29	7.58	8.72	10.22	
25%ile				3.63	4.46	4.59	5.55	7.20	8.02	9.36	11.02	
50%ile				3.70	5.19	5.11	6.70	7.83	8.78	10.28	12.29	
75%ile				4.29	5.58	5.77	7.16	8.74	9.44	11.45	13.32	
95%ile				4.76	6.70	7.03	7.57	9.49	10.52	12.77	14.24	
LCI 95%				2.25	4.66	4.60	6.02	7.50	8.44	10.08	11.82	
UCI 95%				5.85	5.74	6.00	6.84	8.10	9.19	10.78	12.61	

Tooth 24	**Stage**											
(n = 956)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	1	18	16	44	29	28	35	24	44	717
Mean			5.42	4.60	5.69	7.20	7.80	8.50	9.82	10.85	12.37	
SD				0.74	1.03	1.23	1.15	0.98	1.19	1.43	1.44	
SE				0.18	0.26	0.18	0.21	0.19	0.20	0.29	0.22	
Median				4.60	5.52	7.30	7.78	8.74	9.67	10.53	12.39	
Minimum				3.40	3.99	3.93	5.48	6.31	7.96	8.01	9.27	
Maximum				5.82	7.31	9.76	9.74	10.16	12.28	13.59	15.39	
Range				2.42	3.32	5.83	4.26	3.85	4.31	5.57	6.12	
5%ile				3.54	4.16	5.40	5.73	6.65	8.21	9.29	10.25	
10%ile				3.66	4.41	5.67	6.42	7.49	8.29	9.42	10.58	
25%ile				3.94	5.01	6.54	7.16	7.80	9.01	9.91	11.45	
50%ile				4.60	5.52	7.30	7.78	8.74	9.67	10.53	12.39	
75%ile				5.17	6.46	7.90	8.74	9.07	10.61	11.67	13.69	
95%ile				5.60	7.22	8.92	9.50	9.85	11.98	13.53	14.30	
LCI 95%				4.23	5.14	6.83	7.36	8.12	9.41	10.25	11.94	
UCI 95%				4.97	6.24	7.58	8.24	8.88	10.23	11.46	12.81	

Tooth 25	**Stage**											
(n = 1109)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	1	7	21	9	49	34	32	35	22	48	851
Mean		3.94	4.24	5.01	6.70	7.31	8.16	9.32	10.23	11.69	12.40	
SD			0.79	0.73	1.11	1.13	1.00	1.21	1.25	1.52	1.38	
SE			0.30	0.16	0.37	0.16	0.17	0.21	0.21	0.32	0.20	
Median			3.99	5.02	6.72	7.31	8.57	9.07	10.24	11.81	12.57	
Minimum			3.40	3.81	5.52	4.66	5.95	7.28	7.96	9.34	9.27	
Maximum			5.42	6.38	9.05	9.76	9.67	11.97	13.57	14.06	15.39	
Range			2.02	2.57	3.53	5.11	3.72	4.69	5.61	4.72	6.12	
5%ile			3.45	3.93	5.52	5.41	6.31	7.69	8.27	9.61	10.21	
10%ile			3.50	3.95	5.53	5.56	6.81	7.85	8.80	9.84	10.62	
25%ile			3.63	4.51	5.63	6.80	7.41	8.36	9.27	10.25	11.64	
50%ile			3.99	5.02	6.72	7.31	8.57	9.07	10.24	11.81	12.57	
75%ile			4.80	5.54	7.00	7.92	8.86	9.94	10.92	12.96	13.17	
95%ile			5.33	6.25	8.30	8.90	9.49	11.34	12.21	13.92	14.30	
LCI 95%			3.51	4.68	5.85	6.98	7.82	8.88	9.80	11.02	12.00	
UCI 95%			4.97	5.35	7.56	7.63	8.51	9.76	10.66	12.36	12.80	

Tooth 26	Stage											
(n = 1162)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	0	1	5	9	24	13	23	91	996
Mean					3.69	3.96	4.43	5.61	6.19	7.19	8.68	
SD						0.56	0.52	1.09	0.73	0.81	1.33	
SE						0.25	0.17	0.22	0.20	0.17	0.14	
Median						3.70	4.46	5.53	6.25	7.19	8.71	
Minimum						3.40	3.94	3.81	5.37	5.52	4.66	
Maximum						4.62	5.20	8.80	7.78	9.46	13.04	
Range						1.22	1.26	4.99	2.41	3.94	8.38	
5%ile						3.43	3.94	3.98	5.38	5.83	7.09	
10%ile						3.47	3.95	4.35	5.42	6.01	7.23	
25%ile						3.56	3.96	5.07	5.58	7.03	7.82	
50%ile						3.70	4.46	5.53	6.25	7.19	8.71	
75%ile						4.51	4.78	5.86	6.65	7.48	9.25	
95%ile						4.60	5.19	7.25	7.31	8.02	11.00	
LCI 95%						3.26	4.03	5.15	5.75	6.84	8.41	
UCI 95%						4.66	4.83	6.07	6.63	7.54	8.96	

Tooth 27	**Stage**											
(n = 1163)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	11	29	14	37	41	43	39	25	92	832
Mean			4.84	5.94	6.73	7.67	8.10	9.56	10.91	12.47	14.22	
SD			0.85	1.30	1.13	1.29	1.05	1.14	1.51	1.56	1.59	
SE			0.26	0.24	0.30	0.21	0.16	0.17	0.24	0.31	0.17	
Median			4.88	5.52	6.79	7.58	8.04	9.34	10.95	12.17	14.11	
Minimum			3.70	3.81	5.02	4.66	5.95	7.69	6.50	10.24	10.66	
Maximum			5.82	8.94	8.80	10.16	10.28	13.31	14.30	16.85	18.52	
Range			2.12	5.13	3.77	5.50	4.33	5.62	7.80	6.61	7.86	
5%ile			3.82	4.13	5.35	5.31	6.31	8.21	9.14	10.46	11.90	
10%ile			3.93	4.46	5.54	6.26	6.99	8.33	9.33	10.65	12.31	
25%ile			3.97	5.14	5.69	7.09	7.30	8.79	10.10	11.66	12.87	
50%ile			4.88	5.52	6.79	7.58	8.04	9.34	10.95	12.17	14.11	
75%ile			5.64	7.00	7.63	8.77	8.88	10.14	11.76	13.25	15.41	
95%ile			5.79	7.93	8.23	9.58	9.67	11.40	13.11	15.12	16.48	
LCI 95%			4.27	5.44	6.08	7.24	7.77	9.21	10.42	11.83	13.89	
UCI 95%			5.41	6.43	7.39	8.11	8.43	9.91	11.40	13.12	14.55	

Tooth 28	Stage											
(n = 958)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	1	5	25	44	32	60	132	205	135	80	123	116
Mean	7.43	9.17	10.61	11.33	12.69	14.76	14.54	15.25	15.87	16.47	17.34	
SD		1.17	1.85	2.36	2.39	1.66	1.51	1.24	1.43	1.18	1.40	
SE		0.52	0.37	0.36	0.42	0.21	0.13	0.09	0.12	0.13	0.13	
Median		8.77	10.20	10.57	12.60	14.86	14.65	15.29	15.78	16.38	17.20	
Minimum		7.78	8.20	7.96	6.50	10.95	11.00	11.00	12.96	14.30	14.38	
Maximum		10.52	16.27	16.66	18.63	18.38	19.23	20.00	28.22	20.55	23.95	
Range		2.74	8.06	8.70	12.13	7.43	8.23	9.00	15.26	6.25	9.56	
5%ile		7.93	8.64	8.38	9.76	12.16	12.04	13.18	14.24	14.76	15.45	
10%ile		8.08	8.69	9.01	10.56	12.53	12.39	13.68	14.62	15.06	15.66	
25%ile		8.52	9.18	9.48	11.11	13.56	13.50	14.44	15.18	15.63	16.47	
50%ile		8.77	10.20	10.57	12.60	14.86	14.65	15.29	15.78	16.38	17.20	
75%ile		10.24	11.52	13.09	14.20	15.99	15.52	15.92	16.43	17.24	17.95	
95%ile		10.47	13.27	15.42	16.41	17.18	16.79	17.13	17.24	18.35	19.24	
LCI 95%		7.71	9.84	10.62	11.83	14.33	14.28	15.08	15.62	16.21	17.09	
UCI 95%		10.62	11.37	12.05	13.55	15.19	14.80	15.42	16.11	16.73	17.59	

Tooth 18	Stage											
(n = 942)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	5	18	54	30	50	136	192	136	81	123	117
Mean		8.95	10.87	11.31	13.30	14.87	14.40	15.26	15.89	16.36	17.38	
SD		1.15	2.36	2.30	2.20	1.74	1.52	1.13	1.11	1.18	1.38	
SE		0.51	0.56	0.31	0.40	0.25	0.13	0.08	0.10	0.13	0.12	
Median		8.77	10.31	10.63	12.96	15.23	14.37	15.33	15.81	16.32	17.43	
Minimum		7.78	8.20	7.96	9.46	10.95	11.00	11.00	12.96	14.22	14.87	
Maximum		10.87	16.27	17.15	18.38	18.71	19.23	19.17	20.00	20.55	23.95	
Range		3.09	8.06	9.19	8.92	7.76	8.23	8.17	7.04	6.33	9.07	
5%ile		7.93	8.57	8.62	10.30	12.23	12.04	13.40	14.24	14.72	15.45	
10%ile		8.08	8.66	9.10	10.74	12.53	12.41	13.77	14.60	14.98	15.66	
25%ile		8.52	8.87	9.60	11.69	13.57	13.25	14.53	15.19	15.63	16.47	
50%ile		8.77	10.31	10.63	12.96	15.23	14.37	15.33	15.81	16.32	17.43	
75%ile		8.79	11.88	12.24	15.23	15.97	15.46	15.93	16.52	16.98	17.94	
95%ile		10.45	14.90	15.82	16.54	17.57	16.77	16.93	17.58	18.32	19.08	
LCI 95%		7.52	9.70	10.68	12.48	14.38	14.14	15.10	15.70	16.10	17.13	
UCI 95%		10.37	12.04	11.94	14.13	15.37	14.66	15.42	16.08	16.62	17.62	

Tooth 31	Stage											
(n = 1159)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	0	0	3	5	11	21	15	37	1066
Mean						4.13	4.45	5.23	5.51	7.09	7.79	
SD						1.12	0.81	0.70	1.00	1.15	1.03	
SE						0.65	0.36	0.21	0.22	0.30	0.17	
Median						3.56	3.99	5.18	5.52	6.99	7.72	
Minimum						3.40	3.69	3.94	3.81	5.20	4.66	
Maximum						5.42	5.58	6.38	8.00	9.48	9.63	
Range						2.02	1.90	2.44	4.19	4.28	4.97	
5%ile						3.42	3.74	4.23	4.21	5.42	6.31	
10%ile						3.43	3.79	4.51	4.46	5.64	6.85	
25%ile						3.48	3.95	4.78	4.78	6.60	7.23	
50%ile						3.56	3.99	5.18	5.52	6.99	7.72	
75%ile						4.49	5.02	5.73	5.87	7.77	8.53	
95%ile						5.23	5.47	6.10	7.06	9.00	9.53	
LCI 95%						1.35	3.44	4.76	5.06	6.45	7.45	
UCI 95%						6.91	5.46	5.69	5.96	7.73	8.13	

Tooth 32	Stage										
(n = 1161)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	1	2	1	14	21	16	28	59	1019
Mean				3.40	3.63	5.42	4.85	5.41	6.83	7.66	8.85	
SD					0.10		0.84	0.59	1.30	0.80	1.40	
SE					0.07		0.22	0.13	0.33	0.15	0.18	
Median					3.63		4.78	5.44	6.90	7.53	8.77	
Minimum					3.56		3.69	4.46	3.81	6.31	5.95	
Maximum					3.70		6.17	7.06	8.79	9.48	13.57	
Range					0.14		2.48	2.60	4.99	3.17	7.63	
5%ile					3.57		3.85	4.62	4.30	6.61	7.19	
10%ile					3.58		3.94	4.66	5.14	6.78	7.34	
25%ile					3.60		4.05	5.14	6.50	7.17	7.94	
50%ile					3.63		4.78	5.44	6.90	7.53	8.77	
75%ile					3.67		5.65	5.56	7.90	7.92	9.53	
95%ile					3.69		5.98	6.50	8.23	9.04	11.74	
LCI 95%					2.76		4.37	5.14	6.14	7.35	8.48	
UCI 95%					4.50		5.34	5.67	7.53	7.97	9.21	

Tooth 33	Stage										
(n = 1174)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	1	12	14	29	39	46	62	51	920
Mean				5.02	4.43	5.80	6.77	7.06	8.39	10.20	12.24	
SD					0.90	1.66	1.30	1.20	0.87	1.33	1.28	
SE					0.26	0.44	0.24	0.19	0.13	0.17	0.18	
Median					4.10	5.56	6.81	7.16	8.67	10.18	12.28	
Minimum					3.40	3.81	3.95	4.66	5.95	7.81	9.27	
Maximum					6.25	9.67	9.53	9.63	10.16	13.59	14.30	
Range					2.85	5.86	5.57	4.97	4.21	5.78	5.03	
5%ile					3.49	4.23	4.68	5.34	7.21	8.24	10.11	
10%ile					3.58	4.46	5.27	5.54	7.29	8.54	10.52	
25%ile					3.70	4.61	5.52	6.24	7.62	9.29	11.44	
50%ile					4.10	5.56	6.81	7.16	8.67	10.18	12.28	
75%ile					5.15	5.81	7.31	7.78	8.95	10.99	13.19	
95%ile					5.79	9.10	8.77	9.09	9.64	12.38	14.14	
LCI 95%					3.86	4.84	6.27	6.67	8.13	9.87	11.88	
UCI 95%					5.00	6.76	7.26	7.45	8.65	10.54	12.60	

Tooth 34	**Stage**											
(n = 1004)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	1	16	14	25	36	43	36	37	49	747
Mean			3.94	4.46	5.51	6.23	7.56	8.14	9.47	10.77	12.33	
SD				0.70	1.18	1.05	1.04	0.94	0.92	1.33	1.35	
SE				0.18	0.31	0.21	0.17	0.14	0.15	0.22	0.19	
Median				4.49	5.55	6.17	7.39	8.01	9.31	10.63	12.28	
Minimum				3.40	3.93	4.62	5.09	5.95	8.24	7.96	9.27	
Maximum				5.54	7.30	8.80	9.67	9.76	12.40	13.59	14.56	
Range				2.14	3.37	4.18	4.58	3.82	4.16	5.63	5.29	
5%ile				3.52	3.94	4.68	5.71	6.38	8.30	9.05	10.35	
10%ile				3.62	3.96	5.02	6.47	7.13	8.36	9.34	10.63	
25%ile				3.78	4.45	5.52	7.09	7.59	8.80	9.85	11.43	
50%ile				4.49	5.55	6.17	7.39	8.01	9.31	10.63	12.28	
75%ile				5.05	6.15	6.89	8.07	8.87	9.99	11.52	13.25	
95%ile				5.45	7.23	7.92	9.08	9.62	11.01	13.36	14.29	
LCI 95%				4.09	4.83	5.80	7.20	7.85	9.15	10.33	11.95	
UCI 95%				4.84	6.19	6.67	7.91	8.43	9.78	11.21	12.72	

Tooth 35	**Stage**											
(n = 1096)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	6	8	16	16	31	38	30	42	43	69	797
Mean		4.27	4.76	5.60	6.17	7.19	8.01	9.30	10.33	12.08	13.30	
SD		1.25	0.78	2.08	1.15	1.11	1.31	1.35	1.85	1.89	1.55	
SE		0.51	0.28	0.52	0.29	0.20	0.21	0.25	0.29	0.29	0.19	
Median		3.82	5.01	5.11	6.02	7.20	7.80	9.31	9.71	11.71	13.11	
Minimum		3.56	3.40	3.81	4.21	4.66	5.09	5.95	7.96	9.34	9.27	
Maximum		6.81	5.70	12.47	8.80	9.48	13.04	11.97	15.12	17.11	16.79	
Range		3.25	2.30	8.67	4.59	4.82	7.95	6.02	7.16	7.78	7.52	
5%ile		3.59	3.59	3.92	4.51	5.38	6.31	7.34	8.21	9.75	10.85	
10%ile		3.62	3.77	3.97	5.03	5.52	6.62	7.68	8.35	10.03	11.65	
25%ile		3.69	4.33	4.50	5.51	6.62	7.25	8.45	9.03	10.64	12.31	
50%ile		3.82	5.01	5.11	6.02	7.20	7.80	9.31	9.71	11.71	13.11	
75%ile		3.94	5.24	5.64	7.05	7.91	8.79	10.17	11.40	13.24	14.22	
95%ile		6.10	5.60	8.51	7.73	8.89	9.55	11.41	13.56	15.43	15.98	
LCI 95%		2.96	4.11	4.49	5.56	6.78	7.58	8.80	9.75	11.49	12.93	
UCI 95%		5.59	5.42	6.71	6.79	7.60	8.44	9.81	10.91	12.66	13.67	

Tooth 36	Stage											
(n = 1151)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	0	1	2	4	23	16	29	89	987
Mean					3.69	3.48	4.38	5.03	5.99	7.20	8.47	
SD						0.12	0.59	0.87	0.96	1.12	1.18	
SE						0.08	0.29	0.18	0.24	0.21	0.12	
Median						3.48	4.20	5.14	5.75	7.16	8.62	
Minimum						3.40	3.94	3.70	4.68	5.09	4.66	
Maximum						3.56	5.18	6.89	8.80	10.91	13.04	
Range						0.16	1.25	3.19	4.11	5.82	8.38	
5%ile						3.41	3.94	3.82	4.94	5.43	6.85	
10%ile						3.42	3.94	3.94	5.11	5.76	7.23	
25%ile						3.44	3.94	4.33	5.43	6.81	7.78	
50%ile						3.48	4.20	5.14	5.75	7.16	8.62	
75%ile						3.52	4.64	5.57	6.32	7.58	9.10	
95%ile						3.56	5.07	6.33	7.30	8.90	10.13	
LCI 95%						2.44	3.44	4.65	5.48	6.77	8.22	
UCI 95%						4.53	5.32	5.40	6.50	7.63	8.71	

Tooth 37	**Stage**											
(n = 1169)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	1	2	16	25	23	37	22	47	40	35	152	770
Mean	3.40	3.94	5.14	5.89	7.01	7.67	8.19	9.17	11.13	12.36	14.27	
SD			1.57	1.18	1.10	1.01	1.06	1.06	1.38	1.29	1.42	
SE			0.39	0.24	0.23	0.17	0.23	0.15	0.22	0.22	0.12	
Median			4.75	5.52	7.23	7.65	8.44	9.05	10.83	12.28	14.27	
Minimum			3.69	3.81	5.09	4.66	5.95	6.31	9.27	10.09	10.24	
Maximum			10.16	8.80	9.17	9.76	9.87	11.73	14.30	15.39	18.52	
Range			6.48	4.99	4.08	5.11	3.92	5.42	5.03	5.29	8.28	
5%ile			3.70	4.10	5.40	6.24	6.32	7.59	9.35	10.49	12.01	
10%ile			3.82	4.72	5.67	6.68	6.61	8.12	9.51	10.85	12.31	
25%ile			4.16	5.20	6.06	7.16	7.70	8.58	10.14	11.64	13.31	
50%ile			4.75	5.52	7.23	7.65	8.44	9.05	10.83	12.28	14.27	
75%ile			5.61	6.99	7.77	8.04	8.89	9.79	11.98	13.02	15.30	
95%ile			7.33	7.31	8.84	9.49	9.65	11.01	13.60	14.72	16.24	
LCI 95%			4.31	5.40	6.54	7.34	7.72	8.86	10.69	11.92	14.04	
UCI 95%			5.97	6.38	7.49	8.01	8.66	9.48	11.58	12.81	14.50	

Tooth 38	**Stage**											
(n = 952)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	23	16	43	39	57	73	62	201	161	80	108	89
Mean	9.31	10.04	10.93	12.14	13.87	14.47	14.44	15.36	16.13	16.68	17.59	
SD	2.49	1.90	2.25	1.87	1.60	1.56	1.39	1.07	1.18	1.21	1.47	
SE	0.52	0.47	0.34	0.30	0.21	0.18	0.18	0.08	0.09	0.14	0.14	
Median	8.38	9.30	10.38	11.96	14.06	14.58	14.39	15.40	15.97	16.62	17.45	
Minimum	6.55	7.05	7.96	9.34	9.46	10.75	10.95	12.03	13.66	14.00	15.22	
Maximum	15.94	13.12	16.74	16.76	16.60	18.71	18.38	18.20	20.00	20.55	23.95	
Range	9.39	6.07	8.78	7.42	7.13	7.96	7.43	6.16	6.34	6.55	8.72	
5%ile	7.15	7.94	8.22	9.51	10.97	12.14	12.06	13.55	14.36	14.87	15.51	
10%ile	7.46	8.38	8.42	9.98	11.97	12.37	12.69	14.03	14.73	15.20	15.95	
25%ile	7.75	8.69	9.14	10.49	12.53	13.41	13.55	14.72	15.36	15.85	16.49	
50%ile	8.38	9.30	10.38	11.96	14.06	14.58	14.39	15.40	15.97	16.62	17.45	
75%ile	9.75	11.57	12.30	13.38	15.23	15.68	15.53	16.10	16.94	17.36	18.25	
95%ile	15.39	13.11	14.65	14.59	15.95	16.93	16.43	16.93	18.25	18.83	20.16	
LCI 95%	8.23	9.03	10.24	11.53	13.45	14.11	14.09	15.21	15.95	16.41	17.31	
UCI 95%	10.38	11.05	11.63	12.75	14.30	14.83	14.79	15.51	16.32	16.95	17.87	

Tooth 48	**Stage**											
(n = 950)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	17	15	44	39	45	72	69	213	152	86	114	84
Mean	8.51	9.25	11.15	11.66	14.09	14.07	14.77	15.50	16.07	16.57	17.70	
SD	1.20	1.40	2.20	1.45	1.55	1.48	1.41	1.13	1.16	1.28	1.45	
SE	0.29	0.36	0.33	0.23	0.23	0.17	0.17	0.08	0.09	0.14	0.14	
Median	8.52	8.81	10.89	11.79	14.18	14.05	15.05	15.48	15.95	16.40	17.53	
Minimum	6.55	7.05	7.96	9.34	9.46	10.75	10.95	12.03	13.66	14.00	15.22	
Maximum	11.73	12.47	16.29	16.27	16.60	16.85	18.38	18.71	19.53	20.55	23.95	
Range	5.18	5.43	8.33	6.93	7.13	6.10	7.43	6.68	5.87	6.55	8.72	
5%ile	7.00	7.71	8.22	9.51	11.21	11.91	12.68	13.65	14.26	14.87	15.60	
10%ile	7.39	8.09	8.53	9.98	12.26	12.09	12.85	14.08	14.64	15.15	16.11	
25%ile	7.78	8.67	9.27	10.49	13.10	12.86	13.76	14.85	15.31	15.68	16.63	
50%ile	8.52	8.81	10.89	11.79	14.18	14.05	15.05	15.48	15.95	16.40	17.53	
75%ile	9.10	9.96	13.05	12.56	15.25	15.35	15.76	16.37	16.69	17.11	18.62	
95%ile	10.49	12.14	14.60	13.36	16.02	16.39	16.70	17.33	18.08	18.95	20.32	
LCI 95%	7.90	8.47	10.49	11.19	13.62	13.73	14.43	15.34	15.88	16.30	17.44	
UCI 95%	9.13	10.03	11.82	12.13	14.55	14.55	15.11	15.65	16.26	16.85	17.97	

Appendix 9 – Summary Data Set for 12 stages (Females)

Tooth 21	Stage											
(n = 1424)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	1	1	6	9	10	11	27	40	1319
Mean				2.13	2.97	4.54	5.32	5.66	6.38	7.66	8.51	
SD						0.42	0.86	1.12	1.03	1.07	1.43	
SE						0.17	0.29	0.36	0.31	0.21	0.23	
Median						4.60	5.66	5.54	6.34	7.45	8.64	
Minimum						3.95	3.76	3.63	4.19	6.03	5.53	
Maximum						5.12	6.37	8.07	7.66	9.96	11.31	
Range						1.17	2.61	4.44	3.47	3.93	5.78	
5%ile						4.01	4.03	4.28	4.70	6.19	6.51	
10%ile						4.06	4.30	4.93	5.21	6.54	6.85	
25%ile						4.26	4.91	5.38	6.01	6.92	7.35	
50%ile						4.60	5.66	5.54	6.34	7.54	8.64	
75%ile						4.75	5.95	5.67	7.17	8.36	9.55	
95%ile						5.04	6.23	7.41	7.49	9.52	11.02	
LCI 95%						4.09	4.66	4.85	5.69	7.24	8.06	
UCI 95%						4.98	6.46	6.46	7.07	8.09	8.97	

Tooth 22	Stage										
(n = 1365)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	1	1	5	9	12	11	23	35	37	1231
Mean			3.04	2.13	3.64	4.95	5.87	6.27	7.72	8.08	9.43	
SD					1.40	0.77	1.03	1.08	1.31	1.14	1.36	
SE					0.63	0.26	0.30	0.33	0.27	0.19	0.22	
Median					3.76	4.97	5.56	6.24	7.55	8.09	9.51	
Minimum					1.83	3.63	4.44	4.19	5.52	5.53	6.98	
Maximum					5.66	5.95	8.07	8.10	9.96	11.01	13.29	
Range					3.82	2.32	3.64	3.91	4.43	5.48	6.31	
5%ile					2.06	3.85	4.70	4.70	5.71	6.71	7.61	
10%ile					2.29	4.06	4.93	5.21	6.06	6.88	8.01	
25%ile					2.97	4.55	5.29	5.73	6.76	7.03	8.47	
50%ile					3.76	4.97	5.56	6.24	7.55	8.09	9.51	
75%ile					3.95	5.63	6.27	7.00	8.83	8.82	9.92	
95%ile					5.32	5.89	7.63	7.71	9.53	9.64	11.59	
LCI 95%					1.89	4.36	5.21	5.54	7.15	7.69	8.98	
UCI 95%					5.38	5.55	6.53	7.00	8.28	8.47	9.89	

Tooth 23	**Stage**											
(n = 1423)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	3	5	7	24	35	22	49	62	1216
Mean				3.86	4.00	5.83	6.25	7.42	7.93	9.46	11.49	
SD				0.85	0.99	1.35	1.33	1.28	1.09	1.21	1.48	
SE				0.49	0.44	0.51	0.27	0.22	0.23	0.17	0.19	
Median				3.95	3.76	5.95	5.85	7.33	7.86	9.49	11.15	
Minimum				2.97	3.04	4.16	3.63	4.19	5.53	7.18	8.70	
Maximum				4.66	5.12	8.26	9.53	9.96	10.22	13.29	15.30	
Range				1.68	2.09	4.10	5.90	5.77	4.69	6.11	6.60	
5%ile				3.07	3.05	4.28	4.53	5.45	6.64	8.03	9.62	
10%ile				3.17	3.07	4.40	5.03	6.06	6.89	8.25	9.78	
25%ile				3.46	3.12	4.95	5.50	6.74	7.11	8.57	10.36	
50%ile				3.95	3.76	5.95	5.85	7.33	7.86	9.46	11.15	
75%ile				4.31	4.97	6.26	7.13	8.38	8.54	9.95	12.52	
95%ile				4.59	5.09	7.69	8.42	9.19	9.65	11.50	13.83	
LCI 95%				1.76	2.76	4.58	5.69	6.99	7.45	9.11	11.12	
UCI 95%				5.96	5.24	7.08	6.81	7.86	8.42	9.80	11.87	

Tooth 24	**Stage**										
(n = 1148)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	3	8	9	36	16	25	33	26	33	959
Mean			3.30	4.72	5.56	6.94	7.24	8.56	9.28	10.62	11.74	
SD			0.39	0.74	0.95	1.11	1.42	1.08	0.87	1.55	1.66	
SE			0.23	0.26	0.32	0.19	0.35	0.22	0.15	0.30	0.29	
Median			3.12	4.76	5.66	6.94	7.39	8.58	9.44	10.50	11.50	
Minimum			3.04	3.63	3.95	5.07	4.19	6.75	7.18	7.29	8.70	
Maximum			3.76	5.91	7.16	9.53	9.32	10.44	11.11	13.68	15.31	
Range			0.72	2.28	3.20	4.46	5.13	3.69	3.93	6.39	6.61	
5%ile			3.04	3.82	4.15	5.33	5.20	6.99	8.04	8.51	9.72	
10%ile			3.05	4.00	4.34	5.49	5.60	7.17	8.33	8.83	9.93	
25%ile			3.08	4.17	5.21	6.09	6.22	7.92	8.79	9.70	10.60	
50%ile			3.12	4.76	5.66	6.94	7.39	8.58	9.44	10.50	11.50	
75%ile			3.44	5.10	6.03	7.58	8.32	9.49	9.77	11.45	12.76	
95%ile			3.66	5.72	6.75	8.65	9.18	10.22	10.83	13.33	15.15	
LCI 95%			2.32	4.11	4.83	6.56	6.48	8.11	8.98	10.00	11.15	
UCI 95%			4.28	5.34	6.30	7.31	7.99	9.01	9.59	11.25	12.33	

Tooth 25	**Stage**											
(n = 1351)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	2	2	3	9	11	28	23	34	37	24	42	1136
Mean	3.29	3.96	4.16	4.80	6.14	7.15	7.77	8.94	9.94	11.26	12.53	
SD	0.24	0.29	1.02	1.30	0.95	1.03	1.61	1.21	1.45	1.33	1.51	
SE	0.17	0.21	0.59	0.43	0.29	0.19	0.33	0.21	0.24	0.27	0.23	
Median	3.29	3.96	4.44	5.36	6.03	6.98	7.83	8.80	9.63	11.17	12.62	
Minimum	3.12	3.76	3.04	2.28	5.12	5.63	4.19	6.75	7.29	8.57	9.62	
Maximum	3.46	4.17	5.02	6.15	8.02	9.53	11.31	12.96	13.74	13.55	15.30	
Range	0.34	0.41	1.98	3.87	2.89	3.90	7.12	6.21	6.45	4.98	5.69	
5%ile	3.14	3.78	3.18	2.82	5.16	5.67	5.54	7.50	8.27	8.87	10.28	
10%ile	3.15	3.80	3.32	3.36	5.21	5.76	5.79	7.73	8.48	9.95	10.65	
25%ile	3.20	3.86	3.74	3.95	5.48	6.59	6.93	8.04	9.10	10.42	11.16	
50%ile	3.29	3.96	4.44	5.36	6.03	6.98	7.83	8.80	9.63	11.17	12.62	
75%ile	3.37	4.06	4.73	5.91	6.63	7.77	9.59	9.51	10.40	12.27	13.69	
95%ile	3.44	4.15	4.96	6.07	7.67	8.99	10.18	10.82	13.35	13.33	15.02	
LCI 95%	1.13	1.35	1.63	3.80	5.50	6.75	7.08	8.52	9.46	10.70	12.06	
UCI 95%	5.44	6.57	6.70	5.80	6.78	7.55	8.47	9.37	10.43	11.82	13.00	

Tooth 26	**Stage**											
(n = 1392)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	0	0	6	6	15	11	17	67	1270
Mean						3.37	4.06	5.42	6.41	7.32	8.25	
SD						0.80	0.70	0.72	1.16	1.36	1.25	
SE						0.33	0.28	0.19	0.35	0.33	0.15	
Median						3.29	4.06	5.52	6.15	7.16	8.27	
Minimum						2.28	3.04	4.16	5.12	4.19	5.53	
Maximum						4.66	5.02	6.79	9.32	9.96	11.11	
Range						2.38	1.98	2.63	4.20	5.77	5.58	
5%ile						2.45	3.19	4.36	5.26	5.28	6.19	
10%ile						2.63	3.33	4.48	5.40	5.88	6.72	
25%ile						3.01	3.71	5.02	5.62	6.75	7.30	
50%ile						3.29	4.06	5.52	6.15	7.16	8.27	
75%ile						3.68	4.46	5.80	6.83	8.10	9.11	
95%ile						4.43	4.90	6.50	8.14	9.08	10.06	
LCI 95%						2.53	3.33	5.03	5.63	6.62	7.94	
UCI 95%						4.22	4.79	5.82	7.18	8.02	8.55	

Tooth 27	Stage											
(n = 1413)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	3	6	14	15	25	43	41	24	16	105	1121
Mean		3.96	4.45	5.25	6.58	7.44	8.15	9.56	11.07	12.12	13.70	
SD		1.03	0.37	1.11	1.15	1.34	1.11	1.22	1.52	1.68	1.72	
SE		0.60	0.15	0.30	0.30	0.27	0.17	0.19	0.31	0.42	0.17	
Median		3.76	4.49	5.65	6.34	7.40	8.06	9.53	10.97	11.97	13.85	
Minimum		3.04	3.95	2.28	5.12	4.19	5.68	6.98	8.78	9.76	8.70	
Maximum		5.07	5.02	6.37	9.32	9.96	10.72	13.29	15.91	15.66	17.70	
Range		2.04	1.07	4.09	4.20	5.77	5.04	6.31	7.13	5.89	9.00	
5%ile		3.11	4.01	3.16	5.31	5.53	6.64	8.03	8.94	10.10	11.04	
10%ile		3.18	4.06	3.94	5.41	5.77	6.80	8.29	9.60	10.28	11.40	
25%ile		3.40	4.23	5.03	5.66	6.74	7.32	8.87	10.42	10.62	12.41	
50%ile		3.76	4.49	5.65	6.34	7.40	8.06	9.53	10.97	11.97	13.85	
75%ile		4.41	4.56	5.94	7.13	8.46	8.84	9.98	11.14	13.54	15.06	
95%ile		4.94	4.90	6.23	8.45	9.45	9.76	11.31	13.55	14.48	16.12	
LCI 95%		1.39	4.06	4.61	5.95	6.88	7.81	9.17	10.43	11.23	13.37	
UCI 95%		6.52	4.83	5.89	7.22	7.99	8.49	9.95	11.71	13.02	14.03	

Tooth 28	Stage											
(n = 1190)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	6	15	41	34	67	192	262	171	110	151	141
Mean		8.37	10.46	12.84	12.62	14.75	14.53	15.29	16.03	16.29	17.44	
SD		0.84	2.53	2.56	2.34	1.86	1.63	1.50	1.34	1.38	1.21	
SE		0.34	0.65	0.40	0.40	0.23	0.12	0.09	0.10	0.13	0.10	
Median		8.33	10.45	12.96	12.16	15.21	14.86	15.29	15.90	16.12	17.53	
Minimum		7.33	6.98	8.03	8.79	9.76	8.70	12.08	11.12	11.35	14.03	
Maximum		9.84	16.24	16.48	16.41	18.09	18.28	22.74	20.51	22.55	20.22	
Range		2.51	9.25	8.45	7.62	8.33	9.58	10.66	9.39	11.21	6.19	
5%ile		7.48	7.20	9.22	9.71	10.83	11.83	12.99	14.15	14.72	15.59	
10%ile		7.62	7.69	9.53	10.02	12.19	12.27	13.45	14.34	15.10	15.70	
25%ile		7.99	8.75	10.34	10.61	13.69	13.24	14.30	15.21	15.48	16.55	
50%ile		8.33	10.45	12.96	12.16	15.21	14.86	15.29	15.90	16.12	17.53	
75%ile		8.48	11.25	15.21	15.21	15.86	15.70	16.06	16.68	16.86	18.24	
95%ile		9.50	14.44	15.83	15.97	17.41	16.83	17.73	18.66	18.38	19.45	
LCI 95%		7.49	9.06	12.03	11.80	14.30	14.30	15.11	15.82	16.03	17.25	
UCI 95%		9.25	11.86	13.65	13.44	15.20	14.76	15.47	16.23	16.56	17.64	

Tooth 18	**Stage**											
(n = 1177)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	5	17	40	35	73	193	246	162	114	154	138
Mean		8.57	11.41	12.40	13.05	14.71	14.58	15.21	16.15	16.33	17.39	
SD		1.25	2.61	2.31	2.49	1.86	1.62	1.44	1.37	1.32	1.28	
SE		0.56	0.63	0.37	0.42	0.22	0.12	0.09	0.11	0.12	0.10	
Median		8.46	11.64	12.84	12.54	15.06	14.90	15.25	16.07	16.12	17.48	
Minimum		7.33	6.98	8.03	8.79	9.76	8.70	11.35	11.12	14.03	14.03	
Maximum		10.64	16.24	16.65	16.34	18.28	18.28	22.74	20.86	22.55	22.87	
Range		3.31	9.25	8.62	7.55	9.58	9.58	11.39	9.73	8.52	8.84	
5%ile		7.45	8.03	9.18	9.72	11.89	11.89	12.91	14.17	14.58	15.48	
10%ile		7.57	8.52	9.53	10.06	12.27	12.27	13.40	14.45	15.08	15.62	
25%ile		7.92	9.49	10.34	10.73	13.30	13.30	14.30	15.31	15.49	16.47	
50%ile		8.46	11.64	12.84	12.54	14.90	14.90	15.25	16.07	16.12	17.48	
75%ile		8.49	13.68	13.99	15.54	15.70	15.70	15.96	16.81	16.89	18.25	
95%ile		10.21	15.15	15.74	16.09	16.88	16.88	17.09	18.68	18.24	19.13	
LCI 95%		7.01	10.07	11.66	12.19	14.35	14.35	15.03	15.94	16.08	17.18	
UCI 95%		10.12	12.75	13.14	13.90	14.81	14.81	15.39	16.36	16.57	17.59	

Tooth 31	**Stage**											
(n = 1427)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	1	1	4	0	9	10	12	38	1352
Mean				3.04	3.95	3.75		5.04	5.75	6.04	7.89	
SD						0.66		0.99	0.60	0.88	1.11	
SE						0.33		0.33	0.19	0.25	0.18	
Median						3.61		4.97	5.74	6.07	7.75	
Minimum						3.12		3.63	5.07	4.19	5.68	
Maximum						4.66		6.61	7.16	7.09	10.21	
Range						1.54		2.97	2.09	2.90	4.53	
5%ile						3.17		3.85	5.10	4.75	6.23	
10%ile						3.22		4.06	5.12	5.24	6.70	
25%ile						3.27		4.44	5.38	5.54	7.18	
50%ile						3.61		4.97	5.74	6.07	7.75	
75%ile						3.98		5.63	5.94	6.93	8.73	
95%ile						4.52		6.50	6.65	7.06	9.71	
LCI 95%						2.70		4.28	5.32	5.48	7.53	
UCI 95%						4.80		5.80	6.18	6.59	8.26	

Tooth 32	**Stage**											
(n = 1428)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	1	1	3	5	9	12	23	52	1321
Mean				3.04	3.95	3.44	5.06	5.30	6.23	7.27	8.31	
SD						0.32	0.76	0.97	0.90	1.45	1.25	
SE						0.18	0.34	0.32	0.26	0.30	0.17	
Median						3.46	5.12	5.36	6.09	7.04	8.28	
Minimum						3.12	4.16	3.63	5.07	4.19	5.53	
Maximum						3.76	5.95	7.16	8.07	9.96	11.11	
Range						0.64	1.79	3.53	3.00	5.77	5.58	
5%ile						3.15	4.22	4.00	5.15	5.53	6.66	
10%ile						3.19	4.27	4.37	5.23	5.57	6.88	
25%ile						3.29	4.44	4.97	5.69	6.40	7.50	
50%ile						3.46	5.12	5.36	6.09	7.04	8.28	
75%ile						3.61	5.63	5.69	6.53	8.23	9.06	
95%ile						3.73	5.89	6.66	7.70	9.63	10.52	
LCI 95%						2.65	4.12	4.56	5.66	6.64	7.96	
UCI 95%						4.24	6.01	6.05	6.81	7.90	8.66	

Tooth 33	Stage											
(n = 1439)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	2	4	9	12	31	29	53	55	1244
Mean				3.00	3.97	5.31	5.61	7.00	8.03	8.96	11.29	
SD				0.04	0.89	0.92	1.10	1.07	1.52	1.01	1.48	
SE				0.03	0.44	0.31	0.32	0.19	0.28	0.14	0.20	
Median				3.00	3.81	5.07	5.66	7.04	7.99	8.86	11.04	
Minimum				2.97	3.12	3.95	3.63	5.21	4.19	6.75	8.70	
Maximum				3.04	5.12	6.79	8.26	9.96	12.03	11.01	14.98	
Range				0.06	2.00	2.84	4.63	4.75	7.84	4.26	6.28	
5%ile				2.98	3.17	4.19	4.08	5.54	5.97	7.25	9.48	
10%ile				2.98	3.22	4.43	4.49	5.66	6.75	7.83	9.71	
25%ile				2.99	3.37	4.66	5.26	6.20	6.99	8.29	10.26	
50%ile				3.00	3.81	5.07	5.66	7.04	7.99	8.86	11.04	
75%ile				3.02	4.40	5.95	5.94	7.48	8.93	9.62	12.38	
95%ile				3.03	4.98	6.62	7.10	8.52	10.10	10.61	13.92	
LCI 95%				2.60	2.56	4.60	4.91	6.61	7.46	8.68	10.89	
UCI 95%				3.40	5.38	6.01	6.31	7.39	8.61	9.24	11.69	

Tooth 34	**Stage**										
(n = 1187)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	4	6	14	13	27	30	31	40	40	982
Mean			3.45	4.30	5.03	6.12	7.32	8.28	8.93	10.12	11.67	
SD			0.81	1.52	0.78	0.73	0.98	1.38	1.03	1.25	1.54	
SE			0.40	0.62	0.21	0.20	0.19	0.25	0.19	0.20	0.24	
Median			3.08	3.96	5.11	6.03	7.16	8.28	8.81	10.08	11.25	
Minimum			2.97	2.28	3.63	5.12	5.68	4.19	6.75	7.18	8.70	
Maximum			4.66	6.37	6.03	7.32	9.66	10.28	12.54	12.96	15.19	
Range			1.68	4.09	2.40	2.19	3.99	6.08	5.79	5.78	6.49	
5%ile			2.98	2.57	3.84	5.26	6.13	6.07	7.76	8.42	9.61	
10%ile			2.99	2.87	4.02	5.37	6.21	6.94	8.03	8.76	9.90	
25%ile			3.02	3.53	4.47	5.55	6.83	7.66	8.43	9.46	10.64	
50%ile			3.08	3.96	5.11	6.03	7.16	8.28	8.81	10.08	11.25	
75%ile			3.50	5.38	5.61	6.61	7.75	9.29	9.55	10.89	12.84	
95%ile			4.43	6.22	5.98	7.18	9.41	10.17	10.33	12.28	14.13	
LCI 95%			2.16	2.70	4.58	5.68	6.94	7.76	8.56	9.72	11.18	
UCI 95%			4.73	5.90	5.48	6.56	7.71	8.80	9.31	10.51	12.16	

Tooth 35	Stage											
(n = 1318)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	3	0	2	14	13	23	26	30	31	44	72	1063
Mean	3.20		4.15	5.15	5.94	7.19	7.75	8.94	9.86	11.52	12.91	
SD	0.22		2.65	0.91	1.25	0.75	1.43	1.22	1.33	1.85	1.34	
SE	0.13		1.88	0.24	0.35	0.16	0.28	0.22	0.24	0.28	0.16	
Median	3.12		4.15	5.21	5.63	7.09	7.83	8.64	9.68	11.13	12.82	
Minimum	3.04		2.28	3.63	3.95	6.11	4.19	7.18	6.75	8.57	10.34	
Maximum	3.46		6.03	6.79	8.57	9.53	10.21	12.85	13.54	15.55	16.07	
Range	0.42		3.75	3.16	4.62	3.43	6.02	5.66	6.78	6.98	5.72	
5%ile	3.04		2.47	3.98	4.65	6.15	5.57	7.31	8.28	8.79	10.91	
10%ile	3.05		2.65	4.17	5.14	6.25	6.01	7.65	8.49	9.34	11.12	
25%ile	3.08		3.22	4.47	5.36	6.83	6.92	8.04	9.05	10.25	12.05	
50%ile	3.12		4.15	5.21	5.63	7.09	7.83	8.64	9.68	11.13	12.82	
75%ile	3.29		5.09	5.88	6.24	7.50	8.76	9.63	10.49	13.02	13.85	
95%ile	3.42		5.84	6.30	8.35	8.07	9.88	10.52	12.15	14.88	15.10	
LCI 95%	2.65			4.62	5.19	6.87	7.18	8.49	9.38	10.96	12.60	
UCI 95%	3.76			5.67	6.69	7.52	8.33	9.40	10.35	12.08	13.23	

Tooth 36	**Stage**											
(n = 1390)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	0	0	0	0	1	4	4	10	15	19	72	1265
Mean					4.66	3.12	3.44	4.91	6.23	7.02	8.22	
SD						0.65	0.43	0.65	1.09	1.36	1.16	
SE						0.32	0.22	0.21	0.28	0.31	0.14	
Median						3.22	3.38	4.76	5.91	7.04	8.26	
Minimum						2.28	3.04	4.16	5.07	4.19	5.53	
Maximum						3.76	3.95	6.03	9.32	9.96	10.72	
Range						1.48	0.92	1.86	4.25	5.77	5.19	
5%ile						2.38	3.05	4.17	5.11	5.11	6.16	
10%ile						2.49	3.06	4.17	5.22	5.59	6.79	
25%ile						2.80	3.10	4.47	5.42	6.17	7.32	
50%ile						3.22	3.38	4.76	5.91	7.04	8.26	
75%ile						3.53	3.71	5.40	6.77	7.77	8.97	
95%ile						3.71	3.91	5.86	7.67	8.97	9.95	
LCI 95%						2.09	2.74	4.44	5.63	6.36	7.94	
UCI 95%						4.14	4.14	5.37	6.83	7.67	8.49	

Tooth 37	**Stage**										
(n = 1421)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	1	3	6	21	15	34	23	37	32	28	163	1058
Mean	3.46	3.74	4.55	5.36	6.83	7.54	8.17	9.36	10.79	11.99	14.08	
SD		1.15	0.79	1.33	0.96	1.02	1.34	1.07	1.34	1.88	1.41	
SE		0.67	0.32	0.29	0.25	0.17	0.28	0.18	0.24	0.36	0.11	
Median		3.12	4.36	5.44	6.79	7.33	8.09	9.46	10.75	11.71	14.22	
Minimum		3.04	3.76	2.28	5.12	5.53	4.19	6.98	8.78	8.70	10.66	
Maximum		5.07	5.91	9.32	8.57	9.96	10.22	12.96	15.06	15.91	17.19	
Range		2.04	2.15	7.04	3.45	4.43	6.03	5.98	6.28	7.21	6.53	
5%ile		3.04	3.81	3.63	5.59	6.00	6.76	8.16	9.06	9.76	11.66	
10%ile		3.05	3.85	4.17	5.89	6.57	6.89	8.28	9.52	9.87	12.18	
25%ile		3.08	4.01	4.66	6.13	6.90	7.45	8.58	9.79	10.57	12.93	
50%ile		3.12	4.36	5.44	6.79	7.33	8.09	9.46	10.75	11.71	14.22	
75%ile		4.10	4.86	5.69	7.50	8.18	9.00	9.83	11.12	13.36	15.25	
95%ile		4.88	5.67	6.61	8.22	9.27	10.15	10.83	13.05	15.22	16.10	
LCI 95%		0.88	3.72	4.75	6.30	7.19	7.59	9.01	10.30	11.26	13.87	
UCI 95%		6.61	5.38	5.96	7.36	7.90	8.74	9.72	11.27	12.72	14.30	

Tooth 38	Stage											
(n = 1163)	o	Ci	Cco	$C_{1/2}$	$C_{3/4}$	Crc	Ri	$R_{1/4}$	$R_{1/2}$	$R_{3/4}$	Rc	Ac
n-tds	11	13	33	53	64	113	127	245	161	111	140	92
Mean	9.60	9.52	11.44	12.82	14.53	14.60	14.86	15.53	16.37	16.75	17.72	
SD	1.03	2.24	2.08	2.12	1.95	1.89	1.48	1.27	1.57	1.44	1.60	
SE	0.31	0.62	0.36	0.29	0.24	0.18	0.13	0.08	0.12	0.14	0.13	
Median	9.62	8.92	10.86	13.24	15.13	14.71	15.02	15.49	16.10	16.56	17.56	
Minimum	8.46	6.78	8.19	8.03	9.77	8.70	11.67	11.48	11.12	11.35	14.96	
Maximum	11.31	13.60	15.49	16.90	18.28	20.86	22.74	19.15	22.55	20.64	22.78	
Range	2.85	6.81	7.30	8.87	8.51	12.15	11.07	7.66	11.43	9.30	7.82	
5%ile	8.46	6.90	8.48	9.56	10.86	11.27	12.27	13.33	14.34	15.05	15.62	
10%ile	8.46	7.05	8.83	9.84	11.81	12.42	12.84	13.97	14.73	15.23	15.83	
25%ile	8.58	8.27	9.95	11.00	13.07	13.21	14.07	14.93	15.35	15.84	16.56	
50%ile	9.62	8.92	10.86	13.24	15.13	14.71	15.02	15.49	16.10	16.56	17.56	
75%ile	10.17	11.24	12.98	14.79	15.74	15.78	15.71	16.23	17.11	17.62	18.55	
95%ile	11.21	13.34	14.79	15.99	16.80	17.47	16.81	17.62	19.05	19.06	20.97	
LCI 95%	8.91	8.16	10.71	12.24	14.05	14.24	14.60	15.37	16.13	16.47	17.45	
UCI 95%	10.29	10.87	12.18	13.41	15.02	14.95	15.12	15.68	16.61	17.02	17.99	

Tooth 48	**Stage**											
(n = 1155)	**o**	**Ci**	**Cco**	**$C_{1/2}$**	**$C_{3/4}$**	**Crc**	**Ri**	**$R_{1/4}$**	**$R_{1/2}$**	**$R_{3/4}$**	**Rc**	**Ac**
n-tds	11	13	31	52	62	111	131	242	157	108	148	89
Mean	9.49	9.93	11.32	12.68	14.56	14.61	14.91	15.57	16.23	16.49	17.82	
SD	0.88	2.71	1.95	2.00	1.80	1.89	1.58	1.34	1.47	1.32	1.59	
SE	0.26	0.75	0.35	0.28	0.23	0.18	0.14	0.09	0.12	0.13	0.13	
Median	9.62	9.22	11.31	12.88	15.14	14.80	15.02	15.50	16.06	16.28	17.60	
Minimum	8.27	6.78	8.03	9.52	9.77	8.70	11.67	11.48	11.12	11.35	15.18	
Maximum	11.24	15.30	14.82	16.78	18.01	19.35	22.74	19.79	22.55	20.64	22.87	
Range	2.97	8.52	6.79	7.26	8.24	10.64	11.07	8.30	11.43	9.30	7.69	
5%ile	8.37	6.90	8.33	9.68	11.21	11.16	12.27	13.45	14.33	14.96	15.71	
10%ile	8.46	7.05	8.49	10.01	11.91	12.42	12.87	13.97	14.70	15.15	15.90	
25%ile	8.77	8.29	9.93	11.91	13.42	13.29	14.03	14.88	15.31	15.60	16.67	
50%ile	9.62	9.22	11.31	12.88	15.14	14.80	15.02	15.50	16.06	16.28	17.60	
75%ile	9.98	10.86	12.87	14.00	15.72	15.80	15.85	16.31	16.87	17.26	18.65	
95%ile	10.72	14.33	14.29	15.69	16.48	17.46	16.95	17.83	18.66	18.75	20.89	
LCI 95%	8.90	8.29	10.61	12.13	14.10	14.25	14.64	15.40	16.00	16.24	17.56	
UCI 95%	10.08	11.57	12.04	13.24	15.02	14.97	15.18	15.74	16.46	16.74	18.08	

Appendix 10 – Summary Data Set for 8 stages (Males)

Tooth UL1	**Stage**							
(n = 1164)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	0	3	20	27	39	56	1019
Mean			4.32	5.04	6.13	7.47	8.89	
SD			1.12	1.02	1.12	1.32	1.43	
SE			0.64	0.23	0.22	0.21	0.19	
Median			3.99	5.08	6.17	7.58	8.86	
Minimum			3.40	3.56	4.21	4.66	6.31	
Maximum			5.56	7.31	8.79	10.91	12.90	
Range			2.16	3.75	4.58	6.25	6.56	
5%ile			3.46	3.69	4.55	5.36	7.06	
10%ile			3.52	3.80	4.71	5.50	7.14	
25%ile			3.70	4.33	5.43	6.73	7.93	
50%ile			3.99	5.08	6.17	7.58	8.86	
75%ile			4.78	5.55	6.94	8.10	9.75	
95%ile			5.40	7.10	7.80	9.50	11.55	
LCI 95%			1.54	4.56	5.68	7.04	8.51	
UCI 95%			7.09	5.52	6.57	7.89	9.28	

Tooth UL2	**Stage**							
(n = 1135)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	1	13	27	27	57	45	965
Mean		3.40	4.88	5.84	6.44	8.16	9.65	
SD			0.94	1.32	1.20	1.26	1.47	
SE			0.26	0.25	0.23	0.17	0.22	
Median			5.14	5.58	6.50	8.01	9.46	
Minimum			3.56	3.70	4.51	5.44	7.08	
Maximum			6.70	8.90	8.84	11.10	13.60	
Range			3.14	5.20	4.33	5.70	6.49	
5%ile			3.71	4.03	4.63	6.24	7.72	
10%ile			3.83	4.36	4.92	6.61	7.98	
25%ile			3.99	4.94	5.50	7.30	8.71	
50%ile			5.14	5.58	6.50	8.01	9.46	
75%ile			5.56	7.00	7.21	9.05	10.70	
95%ile			6.06	8.04	8.55	10.20	11.99	
LCI 95%			4.31	5.32	5.96	7.83	9.21	
UCI 95%			5.44	6.36	6.91	8.50	10.15	

Tooth UL3	Stage									Tooth UL4	Stage							
(n = 1176)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		**(n= 963)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	0	18	45	68	66	67	912		n-tds	0	6	29	75	48	40	46	719
Mean			4.86	6.59	7.62	9.81	12.10			Mean		4.44	5.00	7.47	8.67	10.50	12.30	
SD			0.93	1.48	1.24	1.50	1.48			SD		0.96	0.86	1.13	1.38	1.37	1.51	
SE			0.22	0.22	0.15	0.18	0.18			SE		0.39	0.16	0.13	0.20	0.22	0.22	
Median			5.08	6.99	7.78	9.83	12.20			Median		4.26	5.09	7.41	8.78	10.30	12.40	
Minimum			3.40	3.81	4.66	5.95	9.04			Minimum		3.40	3.70	4.66	5.58	8.01	8.38	
Maximum			6.50	9.53	10.20	13.60	15.90			Maximum		5.70	7.23	9.83	12.30	13.59	15.39	
Range			3.10	5.72	5.50	7.63	6.85			Range		2.30	3.53	5.17	6.70	5.57	7.01	
5%ile			3.54	4.26	5.49	7.36	9.48			5%ile		3.44	3.86	5.51	6.31	8.96	9.56	
10%ile			3.66	4.56	5.75	7.99	9.97			10%ile		3.48	3.94	5.84	7.07	9.09	10.44	
25%ile			4.01	5.52	6.85	8.89	11.03			25%ile		3.69	4.46	6.76	7.80	9.71	11.44	
50%ile			5.08	6.99	7.78	9.83	12.20			50%ile		4.26	5.09	7.41	8.78	10.30	12.35	
75%ile			5.43	7.65	8.72	10.68	13.10			75%ile		5.22	5.52	8.10	9.41	11.10	13.03	
95%ile			6.41	8.87	9.29	12.11	14.22			95%ile		5.64	6.52	9.26	10.80	13.54	14.30	
LCI 95%			4.44	6.15	7.32	9.44	11.70			LCI 95%		3.43	4.68	7.21	8.27	10.12	11.81	
UCI 95%			5.32	7.04	7.92	10.20	12.53			UCI 95%		5.46	5.33	7.73	9.07	11.01	12.70	

Tooth UL5	Stage							
(n = 1111)	A	B	C	D	E	F	G	H
n-tds	5	7	26	83	52	39	49	850
Mean	4.12	4.69	5.34	7.67	9.36	10.99	12.40	
SD	0.92	0.80	0.85	1.12	1.42	1.58	1.35	
SE	0.41	0.30	0.17	0.12	0.20	0.25	0.19	
Median	3.94	4.46	5.28	7.69	9.21	10.90	12.50	
Minimum	3.40	3.70	3.81	4.66	5.95	6.81	9.27	
Maximum	5.70	5.58	7.23	9.83	13.57	14.10	15.40	
Range	2.30	1.88	3.43	5.17	7.63	7.24	6.12	
5%ile	3.43	3.77	4.08	5.57	7.21	9.02	10.20	
10%ile	3.47	3.84	4.49	6.26	7.79	9.32	10.60	
25%ile	3.56	4.07	4.80	7.08	8.47	9.87	11.74	
50%ile	3.94	4.46	5.28	7.69	9.21	10.90	12.51	
75%ile	3.99	5.47	5.56	8.67	10.26	12.00	13.11	
95%ile	5.36	5.56	7.00	9.46	11.66	13.64	14.30	
LCI 95%	2.98	3.95	4.99	7.43	8.97	10.51	12.15	
UCI 95%	5.26	5.43	5.68	7.92	9.76	11.50	12.79	

Tooth UL6	Stage							
(n = 1165)	A	B	C	D	E	F	G	H
n-tds	0	0	0	17	26	20	105	997
Mean				4.25	5.71	6.48	8.37	
SD				0.61	1.05	0.86	1.35	
SE				0.15	0.21	0.19	0.13	
Median				3.99	5.55	6.52	8.24	
Minimum				3.40	3.81	5.37	4.66	
Maximum				5.43	8.80	8.04	13.04	
Range				2.03	4.99	2.67	8.38	
5%ile				3.53	4.31	5.39	6.58	
10%ile				3.64	4.65	5.43	7.07	
25%ile				3.93	5.07	5.56	7.43	
50%ile				3.99	5.55	6.52	8.24	
75%ile				4.51	6.15	7.30	9.05	
95%ile				5.25	7.23	7.79	10.29	
LCI 95%				3.93	5.29	6.08	8.11	
UCI 95%				4.56	6.13	6.88	8.64	

Tooth UL7	Stage							
(n = 1172)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	3	19	30	84	62	39	99	836
Mean	4.70	4.85	6.35	7.81	9.82	11.60	14.13	
SD	0.91	0.71	1.27	1.13	1.47	1.35	1.62	
SE	0.52	0.16	0.23	0.12	0.19	0.22	0.16	
Median	4.46	4.88	6.44	7.78	9.79	11.52	14.03	
Minimum	3.94	3.70	3.81	4.66	5.95	8.38	10.52	
Maximum	5.70	5.82	8.94	10.28	13.57	14.54	18.52	
Range	1.76	2.12	5.13	5.62	7.63	6.16	8.00	
5%ile	3.99	3.91	4.56	5.87	7.96	9.52	11.87	
10%ile	4.04	3.95	4.99	6.38	8.24	10.20	12.17	
25%ile	4.20	4.14	5.49	7.15	9.01	10.74	12.86	
50%ile	4.46	4.88	6.44	7.78	9.79	11.52	14.03	
75%ile	5.08	5.43	7.22	8.77	10.77	12.43	15.40	
95%ile	5.58	5.76	8.44	9.52	12.11	13.90	16.53	
LCI 95%	2.45	4.51	5.87	7.56	9.44	11.10	13.81	
UCI 95%	6.95	5.19	6.82	8.05	10.24	12.11	14.45	

Tooth UL8	Stage							
(n = 954)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	4	37	54	202	219	194	130	114
Mean	8.83	10.41	12.34	14.52	15.32	16.00	17.37	
SD	1.03	1.69	2.55	1.64	1.24	1.13	1.39	
SE	0.52	0.28	0.35	0.11	0.08	0.08	0.12	
Median	8.64	10.18	11.90	14.58	15.32	15.91	17.21	
Minimum	7.78	8.20	7.96	10.01	11.01	12.96	14.38	
Maximum	10.24	16.27	18.63	19.20	20.00	20.55	23.90	
Range	2.46	8.06	10.67	9.22	9.01	7.59	9.56	
5%ile	7.89	8.29	9.19	11.97	13.32	14.39	15.45	
10%ile	8.00	8.66	9.43	12.24	13.83	14.65	15.60	
25%ile	8.34	9.18	10.40	13.32	14.61	15.28	16.46	
50%ile	8.64	10.18	11.90	14.58	15.32	15.91	17.21	
75%ile	9.13	11.50	14.32	15.63	16.03	16.62	17.94	
95%ile	10.02	12.71	16.81	16.95	17.34	17.88	19.18	
LCI 95%	7.19	9.84	11.63	14.29	15.21	15.84	17.10	
UCI 95%	10.47	11.15	13.11	14.75	15.54	16.16	17.54	

Tooth UR8	Stage							
(n = 944)	A	B	C	D	E	F	G	H
n-tds	8	31	58	191	212	198	130	116
Mean	9.56	10.52	12.40	14.41	15.40	16.00	17.30	
SD	1.24	2.02	2.59	1.65	1.21	1.12	1.37	
SE	0.44	0.36	0.34	0.12	0.08	0.08	0.12	
Median	9.51	10.21	11.72	14.36	15.35	15.91	17.41	
Minimum	7.78	8.20	7.96	10.01	11.00	12.96	14.85	
Maximum	11.03	16.27	18.38	19.23	20.00	20.55	23.90	
Range	3.25	8.06	10.42	9.22	9.00	7.59	9.15	
5%ile	8.04	8.26	9.29	11.96	13.40	14.33	15.45	
10%ile	8.30	8.64	9.57	12.23	13.83	14.64	15.60	
25%ile	8.71	8.93	10.36	13.10	14.61	15.29	16.47	
50%ile	9.51	10.21	11.72	14.36	15.35	15.91	17.41	
75%ile	10.61	11.57	14.93	15.58	16.02	16.64	17.94	
95%ile	10.97	14.59	16.48	16.96	16.99	17.94	19.10	
LCI 95%	8.53	9.73	11.69	14.17	15.21	15.84	17.13	
UCI 95%	10.60	11.15	13.11	14.64	15.45	16.15	17.67	

Tooth LL1	Stage							
(n = 1161)	A	B	C	D	E	F	G	H
n-tds	0	0	1	13	11	27	46	1063
Mean			3.40	4.65	5.17	6.19	7.73	
SD				0.78	0.57	1.15	1.05	
SE				0.22	0.17	0.22	0.15	
Median				5.02	5.48	6.17	7.66	
Minimum				3.56	4.46	4.21	4.66	
Maximum				5.58	5.82	9.48	10.52	
Range				2.02	1.37	5.26	5.86	
5%ile				3.64	4.46	4.66	6.31	
10%ile				3.74	4.46	4.96	6.68	
25%ile				3.95	4.60	5.41	7.17	
50%ile				5.02	5.48	6.17	7.66	
75%ile				5.42	5.64	6.83	8.37	
95%ile				5.52	5.79	7.84	9.44	
LCI 95%				4.18	4.79	5.74	7.42	
UCI 95%				5.12	5.55	6.64	8.04	

Tooth LL2	**Stage**									**Tooth LL3**	**Stage**							
(n = 1165)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		**(n = 1178)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	1	2	20	23	38	66	1015		n-tds	0	1	9	41	70	78	60	919
Mean		3.40	5.31	4.85	5.47	7.41	8.62			Mean		5.43	4.44	6.33	7.33	9.54	12.01	
SD			0.24	0.94	0.93	1.02	1.34			SD			0.76	1.65	1.40	1.46	1.38	
SE			0.17	0.21	0.19	0.17	0.16			SE			0.25	0.25	0.17	0.17	0.18	
Median			5.31	4.95	5.48	7.27	8.45			Median			4.21	6.54	7.29	9.43	12.00	
Minimum			5.14	3.56	4.21	5.37	6.31			Minimum			3.40	3.69	4.62	7.06	9.04	
Maximum			5.48	6.38	7.92	9.48	13.57			Maximum			5.42	9.67	10.21	13.59	14.30	
Range			0.34	2.82	3.71	4.11	7.27			Range			2.02	5.98	5.54	6.53	5.26	
5%ile			5.16	3.68	4.46	5.78	7.09			5%ile			3.47	3.81	5.22	7.30	9.35	
10%ile			5.17	3.70	4.47	6.23	7.22			10%ile			3.53	3.99	5.48	7.72	9.99	
25%ile			5.22	3.95	4.72	6.74	7.69			25%ile			3.94	5.20	6.31	8.56	1.11	
50%ile			5.31	4.95	5.48	7.27	8.45			50%ile			4.21	6.54	7.29	9.43	12.00	
75%ile			5.39	5.61	5.61	7.98	9.15			75%ile			5.14	7.31	8.63	10.41	13.01	
95%ile			5.46	6.26	7.28	9.05	11.03			95%ile			5.32	8.53	9.42	11.91	14.10	
LCI 95%			3.17	4.41	5.07	7.08	8.30			LCI 95%			3.85	5.83	7.00	9.21	11.60	
UCI 95%			7.45	5.29	5.87	7.75	8.95			UCI 95%			5.02	6.84	7.66	9.87	12.31	

Tooth LL4	Stage							
(n = 1007)	A	B	C	D	E	F	G	H
n-tds	0	6	29	60	65	47	55	745
Mean		3.89	5.04	7.24	8.41	10.45	12.08	
SD		0.37	0.86	1.23	1.24	1.41	1.46	
SE		0.15	0.16	0.16	0.15	0.15	0.20	
Median		3.94	5.18	7.27	8.62	10.31	12.14	
Minimum		3.40	3.69	4.66	5.58	7.96	8.38	
Maximum		4.46	6.99	9.76	11.13	13.59	14.56	
Range		1.06	3.31	5.11	5.56	5.63	6.18	
5%ile		3.44	3.74	5.38	6.31	8.21	9.68	
10%ile		3.48	3.91	5.52	6.82	8.77	10.29	
25%ile		3.66	4.46	6.65	7.63	9.31	10.88	
50%ile		3.94	5.18	7.27	8.62	10.31	12.14	
75%ile		4.03	5.54	7.92	9.26	11.21	13.10	
95%ile		4.36	6.43	9.05	10.24	13.01	14.29	
LCI 95%		3.51	4.72	6.93	8.06	9.95	11.68	
UCI 95%		4.29	5.37	7.55	8.72	10.81	12.51	

Tooth LL5	Stage							
(n = 1100)	A	B	C	D	E	F	G	H
n-tds	11	5	28	75	49	65	69	798
Mean	4.41	4.74	5.53	7.72	9.29	11.71	13.16	
SD	1.09	0.70	1.10	1.47	1.58	2.06	1.59	
SE	0.33	0.31	0.21	0.17	0.23	0.26	0.19	
Median	3.94	4.88	5.46	7.65	9.12	11.53	12.98	
Minimum	3.40	3.99	3.81	4.66	5.95	8.20	9.27	
Maximum	6,81	5.58	8.80	13.04	13.57	17.11	16.79	
Range	3.41	1.59	4.99	8.38	7.63	8.91	7.52	
5%ile	3.48	4.01	4.04	5.52	7.08	8.73	10.68	
10%ile	3.56	4.02	4.38	5.99	7.37	9.17	11.29	
25%ile	3.69	4.06	4.75	6.97	8.28	10.21	12.18	
50%ile	3.94	4.88	5.46	7.65	9.12	11.53	12.98	
75%ile	4.94	5.18	5.93	8.63	10.20	13.10	14.19	
95%ile	6.26	5.50	7.25	9.81	12.20	15.21	15.95	
LCI 95%	3.68	3.87	5.11	7.39	8.83	11.10	12.78	
UCI 95%	5.15	5.61	5.96	8.06	9.74	12.21	13.54	

Tooth LL6	Stage							
(n = 1154)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	0	0	9	27	30	100	988
Mean				4.18	5.06	6.72	8.29	
SD				0.71	0.82	1.33	1.34	
SE				0.24	0.16	0.24	0.13	
Median				3.94	5.20	6.62	8.18	
Minimum				3.41	3.70	5.02	4.66	
Maximum				5.43	6.89	10.91	14.25	
Range				2.03	3.19	5.88	9.60	
5%ile				3.47	3.85	5.22	6.54	
10%ile				3.53	3.95	5.39	7.06	
25%ile				3.69	4.49	5.61	7.39	
50%ile				3.94	5.20	6.62	8.18	
75%ile				4.46	5.58	7.27	8.94	
95%ile				5.33	6.21	9.17	10.16	
LCI 95%				3.64	4.74	6.23	8.02	
UCI 95%				4.73	5.39	7.22	8.56	

Tooth LL7	Stage							
(n = 1180)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	4	23	33	67	65	53	154	781
Mean	4.43	5.25	6.21	7.77	9.53	11.80	14.21	
SD	0.46	1.55	1.01	1.01	1.37	1.58	1.44	
SE	0.23	0.32	0.18	0.12	0.17	0.22	0.12	
Median	4.21	5.18	6.25	7.78	9.46	11.82	14.24	
Minimum	3.94	3.69	3.81	4.66	5.95	8.38	10.24	
Maximum	4.88	10.16	8.01	9.87	13.57	15.39	18.52	
Range	0.94	6.48	4.21	5.21	7.63	7.01	8.28	
5%ile	3.94	3.72	4.89	6.19	7.53	9.37	12.01	
10%ile	3.94	3.94	5.09	6.61	8.08	9.92	12.25	
25%ile	3.94	4.14	5.48	7.18	8.79	10.73	13.07	
50%ile	4.21	5.18	6.25	7.78	9.46	11.82	14.24	
75%ile	4.56	5.55	7.00	8.66	10.28	12.80	15.25	
95%ile	4.82	8.56	7.63	9.21	11.66	14.41	16.20	
LCI 95%	3.58	4.58	5.84	7.52	9.17	11.36	13.99	
UCI 95%	5.03	5.92	6.56	8.01	9.87	12.24	14.40	

Tooth LL8	Stage							
(n = 929)	A	B	C	D	E	F	G	H
n-tds	24	46	70	150	219	217	116	87
Mean	9.87	11.32	13.30	14.41	15.39	16.33	17.61	
SD	1.66	2.13	1.94	1.49	1.09	1.21	1.52	
SE	0.34	0.31	0.23	0.12	0.07	0.08	0.14	
Median	9.14	11.03	13.50	14.28	15.42	16.25	17.47	
Minimum	7.05	7.96	9.34	10.79	12.01	13.66	15.20	
Maximum	13.1	16.74	16.76	18.71	20.00	20.55	23.95	
Range	6.07	8.78	7.42	7.96	7.97	6.89	8.75	
5%ile	8.25	8.24	9.91	12.06	13.72	14.43	15.53	
10%ile	8.38	9.04	10.40	12.40	14.13	14.87	15.95	
25%ile	8.75	9.54	12.00	13.41	14.81	15.48	16.48	
50%ile	9.14	11.03	13.50	14.28	15.42	16.18	17.47	
75%ile	11.01	12.93	14.71	15.51	16.15	17.07	18.26	
95%ile	13.00	14.63	16.11	16.48	17.02	18.55	20.33	
LCI 95%	9.16	10.71	12.84	14.13	15.32	16.16	17.33	
UCI 95%	10.62	11.96	13.76	14.61	15.56	16.49	17.89	

Tooth LR8	Stage							
(n = 931)	A	B	C	D	E	F	G	H
n-tds	25	45	57	154	233	218	112	87
Mean	9.71	11.19	13.16	14.37	15.47	16.30	17.59	
SD	1.60	1.87	2.01	1.49	1.17	1.23	1.42	
SE	0.32	0.28	0.26	0.12	0.08	0.08	0.13	
Median	9.05	11.07	13.10	14.38	15.48	16.12	17.46	
Minimum	7.05	7.96	9.34	10.52	12.01	13.66	15.20	
Maximum	14.21	14.66	16.60	18.38	19.53	20.55	23.95	
Range	9.17	6.70	7.26	7.86	7.52	6.89	8.75	
5%ile	8.05	8.23	9.77	12.03	13.63	14.44	15.58	
10%ile	8.27	8.88	10.21	12.25	14.15	14.87	15.98	
25%ile	8.81	9.59	11.91	13.42	14.79	15.47	16.50	
50%ile	9.05	11.07	13.10	14.38	15.48	16.12	17.46	
75%ile	10.23	12.89	14.71	15.53	16.37	16.98	18.35	
95%ile	12.42	14.27	16.21	16.62	17.40	18.73	20.14	
LCI 95%	9.05	10.63	12.63	14.13	15.40	16.14	17.32	
UCI 95%	10.44	11.82	13.72	14.61	15.74	16.47	17.86	

Appendix 11 – Summary Data Set for 8 stages (Females)

Tooth UL1	Stage							
(n = 1426)	A	B	C	D	E	F	G	H
n-tds	0	1	2	13	19	24	47	1320
Mean		2.13	2.4	4.84	5.86	7.13	8.46	
SD			0.81	0.98	1.12	1.12	1.37	
SE			0.57	0.27	0.26	0.23	0.19	
Median			2.40	4.78	5.66	7.03	8.57	
Minimum			1.83	3.04	3.63	4.19	5.53	
Maximum			2.97	6.37	8.07	9.53	11.31	
Range			1.14	3.33	4.44	5.34	5.78	
5%ile			1.89	3.47	4.36	6.04	6.57	
10%ile			1.95	3.80	4.82	6.13	6.89	
25%ile			2.12	4.16	5.28	6.64	7.33	
50%ile			2.40	4.78	5.66	7.03	8.57	
75%ile			2.69	5.63	6.38	7.56	9.49	
95%ile			2.92	6.16	7.70	9.19	11.01	
LCI 95%				4.25	5.32	6.65	8.06	
UCI 95%				5.44	6.39	7.61	8.86	

Tooth UL2	Stage							
(n = 1365)	A	B	C	D	E	F	G	H
n-tds	0	2	5	19	22	43	42	1232
Mean		2.94	3.49	5.64	6.79	7.69	9.44	
SD		1.15	1.43	1.09	1.39	1.19	1.32	
SE		0.81	0.64	0.25	0.31	0.18	0.20	
Median		2.94	3.04	5.63	6.58	7.83	9.51	
Minimum		2.13	1.83	3.63	4.44	4.19	6.98	
Maximum		3.76	5.66	8.07	9.53	9.66	13.29	
Range		1.62	3.82	4.44	5.10	5.47	6.31	
5%ile		2.21	2.06	4.11	4.93	5.71	7.71	
10%ile		2.30	2.29	4.47	5.23	6.65	8.03	
25%ile		2.54	2.97	5.02	5.64	6.91	8.47	
50%ile		2.94	3.04	5.63	6.58	7.83	9.51	
75%ile		3.35	3.95	6.09	7.64	8.59	9.95	
95%ile		3.59	5.32	7.39	9.07	9.63	11.46	
LCI 95%			1.72	5.11	6.17	7.32	9.03	
UCI 95%			5.26	6.17	7.41	8.06	9.85	

Tooth UL3	Stage									Tooth UL4	Stage							
(n = 1425)	A	B	C	D	E	F	G	H		(n = 1147)	A	B	C	D	E	F	G	H
n-tds	0	1	8	24	42	67	68	1215		n-tds	1	3	16	53	42	36	39	957
Mean		3.04	4.24	6.14	7.16	9.02	11.42			Mean	3.04	4.50	4.89	7.29	8.64	9.94	11.81	
SD			0.92	1.39	1.16	1.28	1.45			SD		1.21	0.82	1.15	1.23	1.29	1.68	
SE			0.32	0.28	0.18	0.16	0.18			SE		0.70	0.22	0.16	0.19	0.21	0.27	
Median			4.31	5.87	7.01	8.86	11.13			Median		5.02	5.02	7.16	8.78	9.72	11.52	
Minimum			2.97	3.63	4.19	5.53	8.70			Minimum		3.12	3.63	5.40	4.19	7.29	8.70	
Maximum			5.36	9.53	9.32	13.29	15.30			Maximum		5.36	6.15	10.21	11.01	12.54	15.31	
Range			2.38	5.90	5.13	7.76	6.60			Range		2.24	2.52	4.81	6.81	5.25	6.61	
5%ile			3.02	4.21	5.45	7.21	9.62			5%ile		3.31	3.73	5.59	6.88	8.05	9.61	
10%ile			3.07	4.47	5.68	7.65	9.77			10%ile		3.50	3.85	5.72	7.20	8.53	9.92	
25%ile			3.60	5.32	6.57	8.28	10.34			25%ile		4.07	4.17	6.55	8.04	9.05	10.55	
50%ile			4.31	5.87	7.01	8.86	11.13			50%ile		5.02	5.02	7.16	8.78	9.72	11.52	
75%ile			5.01	7.13	7.97	9.65	12.43			75%ile		5.19	5.57	8.07	9.52	10.64	13.05	
95%ile			5.28	8.23	8.99	10.95	13.79			95%ile		5.32	6.06	9.26	10.21	12.39	15.09	
LCI 95%			3.47	5.51	6.79	8.71	11.10			LCI 95%		1.51	4.45	6.97	0.37	9.51	11.20	
UCI 95%			5.01	6.68	7.52	9.33	11.83			UCI 95%		7.50	5.32	7.61	8.26	10.40	12.31	

Tooth UL5	Stage									Tooth UL6	Stage							
(n = 1351)	A	B	C	D	E	F	G	H		(n = 1395)	A	B	C	D	E	F	G	H
n-tds	4	6	14	52	51	39	47	1137		n-tds	0	0	1	12	15	14	81	1271
Mean	3.60	4.48	5.54	7.64	9.04	10.71	12.42			Mean			3.46	4.00	5.31	6.72	8.14	
SD	0.48	1.37	0.75	1.18	1.69	1.50	1.52			SD				1.19	0.62	1.08	1.22	
SE	0.24	0.56	0.19	0.18	0.24	0.24	0.22			SE				0.34	0.16	0.29	0.14	
Median	3.61	4.73	5.54	7.39	8.87	10.39	12.62			Median				3.85	5.36	6.76	8.21	
Minimum	3.04	2.28	3.95	5.63	4.19	8.09	9.62			Minimum				2.28	4.16	5.44	5.53	
Maximum	4.17	6.15	7.16	11.31	15.10	13.74	15.30			Maximum				6.79	6.37	9.32	11.01	
Range	1.13	3.87	3.20	5.68	10.87	5.65	5.69			Range				4.51	2.20	3.88	5.48	
5%ile	3.10	2.62	4.34	5.93	6.81	8.69	10.30			5%ile				2.66	4.36	5.49	6.17	
10%ile	3.16	2.96	4.72	6.25	7.36	8.89	10.54			10%ile				2.98	4.48	5.53	6.62	
25%ile	3.35	3.83	5.25	6.89	8.23	9.64	11.14			25%ile				3.10	5.02	5.96	7.18	
50%ile	3.61	4.73	5.54	7.39	8.87	10.39	12.62			50%ile				3.85	5.36	6.76	8.21	
75%ile	3.86	5.27	5.97	8.47	9.79	11.72	13.63			75%ile				4.58	5.67	7.03	8.93	
95%ile	4.11	5.95	6.47	9.51	11.30	13.38	14.94			95%ile				5.82	6.13	8.51	9.96	
LCI 95%	2.84	3.04	5.11	7.31	8.57	10.20	12.01			LCI 95%				3.24	4.96	6.09	7.87	
UCI 95%	4.36	5.92	5.97	7.97	9.52	11.20	12.90			UCI 95%				4.75	5.63	7.34	8.41	

Tooth UL7	Stage							
(n = 1417)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	2	12	15	81	46	26	110	1124
Mean	3.79	4.35	6.43	7.82	9.81	11.30	13.59	
SD	1.07	0.89	1.40	1.32	1.29	1.55	1.74	
SE	0.76	0.26	0.36	0.14	0.19	0.33	0.17	
Median	3.79	4.50	6.03	7.92	9.82	10.71	13.82	
Minimum	3.04	2.28	5.21	4.19	6.98	8.83	8.77	
Maximum	4.55	5.69	9.83	10.70	13.31	15.70	17.71	
Range	1.51	3.41	4.62	6.52	6.31	6.83	9.01	
5%ile	3.11	3.02	5.31	5.68	8.07	9.59	10.81	
10%ile	3.19	3.65	5.39	6.17	8.38	9.69	11.25	
25%ile	3.41	3.90	5.58	6.92	8.92	10.36	12.28	
50%ile	3.79	4.50	6.03	7.92	9.82	10.71	13.82	
75%ile	4.17	4.98	6.62	8.64	10.61	12.42	15.09	
95%ile	4.47	5.38	9.47	9.77	11.51	13.55	16.16	
LCI 95%	1.48	3.79	5.66	7.53	9.43	10.60	13.30	
UCI 95%	5.83	4.92	7.21	8.11	10.22	11.91	13.91	

Tooth UL8	Stage							
(n = 1186)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	9	21	56	267	273	262	158	140
Mean	9.27	11.01	12.90	14.55	15.28	16.11	17.47	
SD	1.92	2.59	2.49	1.73	1.54	1.27	1.33	
SE	0.64	0.56	0.33	0.11	0.09	0.08	0.11	
Median	8.49	10.72	12.91	14.98	15.31	16.01	17.53	
Minimum	7.33	6.98	8.47	8.70	12.08	11.12	14.03	
Maximum	13.68	15.21	16.48	18.28	22.69	21.37	22.55	
Range	6.35	8.22	8.01	9.58	10.77	10.24	8.53	
5%ile	7.57	7.29	9.53	11.54	12.99	14.28	15.58	
10%ile	7.81	8.03	9.87	12.22	13.51	14.68	15.69	
25%ile	8.19	8.83	10.50	13.24	14.33	15.33	16.47	
50%ile	8.49	10.72	12.91	14.98	15.31	16.01	17.53	
75%ile	9.51	13.52	15.51	15.71	16.08	16.82	18.36	
95%ile	12.51	15.24	16.30	16.88	17.80	18.32	19.79	
LCI 95%	7.80	9.85	12.22	14.31	15.09	16.01	17.32	
UCI 95%	10.72	12.20	15.54	14.74	15.54	16.33	17.77	

Tooth UR8	Stage							
(n = 1183)	A	B	C	D	E	F	G	H
n-tds	8	23	59	270	260	261	161	141
Mean	9.31	11.10	13.01	14.56	15.35	16.23	17.41	
SD	1.95	2.21	2.43	1.73	1.51	1.23	1.38	
SE	0.69	0.46	0.32	0.11	0.09	0.08	0.11	
Median	8.85	10.95	12.92	14.93	15.36	16.09	17.48	
Minimum	7.33	6.98	8.47	8.70	11.35	11.12	14.03	
Maximum	13.68	14.88	16.70	18.33	22.71	21.37	22.87	
Range	6.35	7.90	8.18	9.58	11.40	10.24	8.84	
5%ile	7.54	8.06	9.53	11.38	12.93	14.29	15.47	
10%ile	7.74	8.37	9.93	12.24	13.43	14.73	15.61	
25%ile	8.33	9.66	10.60	13.24	14.35	15.38	16.33	
50%ile	8.85	10.95	12.92	14.93	15.29	16.09	17.48	
75%ile	9.60	12.99	15.33	15.64	16.03	16.83	18.33	
95%ile	12.33	14.64	16.21	16.94	17.84	18.13	19.30	
LCI 95%	7.68	10.22	12.31	14.31	15.15	15.99	17.22	
UCI 95%	10.91	12.12	13.62	14.74	15.55	16.03	17.64	

Tooth LL1	Stage							
(n = 1428)	A	B	C	D	E	F	G	H
n-tds	0	0	3	4	11	16	42	1352
Mean			3.32	3.75	5.19	5.94	7.71	
SD			0.55	0.66	0.84	0.82	1.21	
SE			0.32	0.33	0.25	0.22	0.19	
Median			3.04	3.61	5.12	5.74	7.56	
Minimum			2.97	3.12	3.63	4.44	4.19	
Maximum			3.95	4.66	6.34	7.16	9.96	
Range			0.98	1.54	2.71	2.72	5.77	
5%ile			2.98	3.17	3.90	4.91	6.04	
10%ile			2.99	3.22	4.16	5.14	6.28	
25%ile			3.00	3.37	4.76	5.42	6.97	
50%ile			3.04	3.61	5.12	5.74	7.56	
75%ile			3.49	3.98	5.81	6.33	8.56	
95%ile			3.86	4.52	6.19	7.11	9.53	
LCI 95%			1.96	2.70	4.63	5.48	7.33	
UCI 95%			4.68	4.81	5.75	6.32	8.09	

Tooth LL2	Stage							
(n = 1428)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	0	3	9	11	27	57	1321
Mean			3.32	4.60	5.39	6.92	8.14	
SD			0.55	1.25	0.62	1.21	1.31	
SE			0.32	0.42	0.19	0.23	0.17	
Median			3.04	4.16	5.36	6.87	8.06	
Minimum			2.97	3.12	4.44	5.07	4.19	
Maximum			3.95	6.61	6.24	9.49	11.01	
Range			0.98	3.49	1.80	4.41	6.82	
5%ile			2.98	3.25	4.49	5.41	5.96	
10%ile			2.99	3.39	4.55	5.49	6.83	
25%ile			3.00	3.63	4.99	6.01	7.32	
50%ile			3.04	4.16	5.36	6.87	8.06	
75%ile			3.49	5.63	5.86	7.42	8.92	
95%ile			3.86	6.34	6.19	9.26	10.08	
LCI 95%			1.96	3.64	4.98	6.45	7.79	
UCI 95%			4.68	5.57	5.81	7.40	8.48	

Tooth LL3	Stage							
(n = 1441)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	2	4	21	37	74	57	1246
Mean		3.08	3.99	5.42	7.12	8.62	11.16	
SD		0.06	1.04	1.06	1.53	1.08	1.54	
SE		0.04	0.52	0.23	0.25	0.13	0.21	
Median		3.08	3.81	5.41	6.99	8.59	10.96	
Minimum		3.04	2.97	3.63	4.19	5.53	7.69	
Maximum		3.12	5.36	8.02	12.03	11.01	14.98	
Range		0.08	2.38	4.38	7.84	5.48	7.29	
5%ile		3.04	3.05	3.76	5.35	6.75	9.15	
10%ile		3.04	3.12	3.95	5.54	7.16	9.66	
25%ile		3.06	3.34	4.66	6.03	8.04	10.23	
50%ile		3.08	3.81	5.42	6.99	8.59	10.96	
75%ile		3.10	4.46	6.15	7.55	9.48	12.32	
95%ile		3.11	5.18	6.79	9.96	10.31	13.93	
LCI 95%		2.56	2.34	4.92	6.61	8.37	10.75	
UCI 95%		3.60	5.64	5.89	7.63	8.87	11.55	

Tooth LL4	Stage							
(n = 1187)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	2	4	12	41	52	53	41	982
Mean	3.08	3.76	4.87	6.75	8.29	9.77	11.50	
SD	0.06	0.85	1.22	1.29	1.28	1.43	1.53	
SE	0.04	0.43	0.35	0.20	0.18	0.21	0.24	
Median	3.08	3.55	5.01	6.88	8.47	9.68	11.14	
Minimum	3.04	2.97	2.28	4.17	4.19	6.75	8.70	
Maximum	3.12	4.97	6.37	10.21	10.32	13.02	15.19	
Range	0.08	1.99	4.09	6.04	6.08	6.21	6.49	
5%ile	3.04	3.05	3.09	5.02	5.91	7.25	9.62	
10%ile	3.04	3.12	3.78	5.21	6.79	8.07	9.77	
25%ile	3.06	3.34	4.11	5.69	7.53	8.81	10.41	
50%ile	3.08	3.55	5.01	6.88	8.47	9.68	11.14	
75%ile	3.10	3.97	5.85	7.55	9.23	10.62	12.78	
95%ile	3.11	4.77	6.25	8.68	9.95	12.30	14.13	
LCI 95%	2.56	2.40	4.10	6.34	7.93	9.38	11.03	
UCI 95%	3.63	5.11	5.65	7.16	8.65	10.21	12.19	

Tooth LL5	Stage							
(n = 1320)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	1	6	16	49	50	58	79	1061
Mean	3.63	4.82	5.31	7.46	8.94	11.15	12.83	
SD		1.43	0.82	1.09	1.62	1.99	1.37	
SE		0.58	0.20	0.16	0.23	0.26	0.15	
Median		5.01	5.42	7.32	8.96	10.62	12.84	
Minimum		2.28	3.95	5.63	4.19	7.69	10.26	
Maximum		6.15	6.79	10.20	13.51	16.76	16.81	
Range		3.87	2.84	4.57	9.32	9.07	5.91	
5%ile		2.82	4.11	5.77	6.74	8.68	10.65	
10%ile		3.36	4.17	6.07	7.15	8.82	11.01	
25%ile		4.49	4.91	6.88	8.11	9.76	11.97	
50%ile		5.01	5.42	7.32	8.96	10.62	12.74	
75%ile		5.86	5.71	8.09	9.65	12.54	13.67	
95%ile		6.12	6.65	9.42	11.31	15.05	15.08	
LCI 95%		3.32	4.88	7.15	8.48	10.62	12.47	
UCI 95%		6.31	5.75	7.77	9.44	11.70	13.14	

Tooth LL6	Stage									Tooth LL7	Stage							
(n = 1388)	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**		**(n = 1421)**	**A**	**B**	**C**	**D**	**E**	**F**	**G**	**H**
n-tds	0	0	0	8	13	17	85	1265		n-tds	3	12	21	65	51	43	167	1060
Mean				3.43	5.12	6.34	8.03			Mean	3.74	4.62	5.82	7.68	9.61	11.37	14.01	
SD				0.73	0.78	1.07	1.24			SD	1.15	0.70	1.33	1.15	1.13	1.81	1.43	
SE				0.26	0.22	0.26	0.13			SE	0.67	0.20	0.29	0.14	0.16	0.28	0.11	
Median				3.38	5.02	6.24	8.10			Median	3.12	4.55	5.79	7.66	9.60	10.86	14.12	
Minimum				2.28	4.16	5.07	4.19			Minimum	3.04	3.63	2.28	4.19	6.98	8.70	10.71	
Maximum				4.66	6.79	9.32	10.72			Maximum	5.04	5.69	9.32	10.22	12.96	15.91	17.20	
Range				2.38	2.63	4.25	6.52			Range	2.04	2.05	7.04	6.03	5.98	7.21	6.53	
5%ile				2.52	4.17	5.18	6.04			5%ile	3.04	3.70	4.17	6.17	8.23	9.26	11.49	
10%ile				2.76	4.22	5.32	6.43			10%ile	3.05	3.78	5.02	6.43	8.47	9.59	12.08	
25%ile				3.02	4.55	5.52	7.16			25%ile	3.08	4.11	5.36	6.92	8.82	10.21	12.91	
50%ile				3.38	5.02	6.24	8.10			50%ile	3.12	4.55	5.79	7.66	9.60	10.89	14.12	
75%ile				3.81	5.66	6.96	8.87			75%ile	4.10	5.08	6.15	8.46	10.12	12.14	15.25	
95%ile				4.41	6.33	7.82	9.81			95%ile	4.88	5.66	7.45	9.52	11.46	15.08	16.12	
LCI 95%				2.82	4.65	5.79	7.76			LCI 95%	0.88	4.18	5.22	7.39	0.31	10.79	13.76	
UCI 95%				4.03	5.61	6.89	8.32			UCI 95%	6.61	5.06	6.43	7.96	9.29	11.93	14.23	

Tooth LL8	Stage							
(n = 1150)	A	B	C	D	E	F	G	H
n-tds	14	38	87	260	264	248	149	90
Mean	9.78	11.58	13.70	14.74	15.60	16.46	17.67	
SD	2.39	2.19	2.21	1.73	1.38	1.61	1.61	
SE	0.64	0.36	0.24	0.11	0.08	0.09	0.13	
Median	9.22	11.08	13.82	14.91	15.50	16.29	17.52	
Minimum	6.78	8.03	9.22	8.70	11.48	11.14	14.96	
Maximum	13.71	15.49	18.28	22.70	21.69	22.60	22.78	
Range	6.89	7.46	9.06	14.01	10.21	11.54	7.82	
5%ile	6.91	8.43	9.78	11.91	13.31	14.51	15.61	
10%ile	7.09	8.72	10.42	12.39	13.97	14.99	15.83	
25%ile	8.27	9.96	12.32	13.61	14.98	15.58	16.47	
50%ile	9.22	11.08	13.84	14.91	15.50	16.29	17.52	
75%ile	11.32	13.07	15.20	15.73	16.27	17.31	18.58	
95%ile	16.63	15.03	16.73	16.88	17.83	18.87	20.77	
LCI 95%	8.64	10.81	14.32	14.53	15.43	16.28	17.41	
UCI 95%	11.25	12.33	14.11	14.96	15.76	16.73	17.95	

Tooth LR8	Stage							
(n = 1143)	A	B	C	D	E	F	G	H
n-tds	16	36	88	256	257	247	151	92
Mean	9.84	11.69	13.73	14.68	15.63	16.32	17.79	
SD	2.28	2.01	2.11	1.74	1.39	1.39	1.61	
SE	0.57	0.34	0.22	0.11	0.09	0.09	0.13	
Median	9.51	11.40	13.87	14.95	15.53	16.13	17.60	
Minimum	6.78	8.19	9.22	8.70	11.48	11.44	15.18	
Maximum	13.71	15.32	18.01	19.35	21.37	22.66	22.87	
Range	6.89	7.13	8.79	10.64	9.88	11.46	7.69	
5%ile	6.93	8.48	9.82	11.77	13.40	14.44	15.67	
10%ile	7.15	9.29	10.48	12.45	13.97	14.95	15.87	
25%ile	8.23	10.33	12.34	13.71	14.98	15.51	16.61	
50%ile	9.51	11.40	13.87	14.95	15.53	16.11	17.60	
75%ile	11.01	13.10	15.37	15.79	16.34	17.03	18.67	
95%ile	13.63	14.92	16.40	16.91	17.97	18.72	20.89	
LCI 95%	8.62	10.99	13.39	14.47	15.46	16.20	17.53	
UCI 95%	11.02	12.42	14.19	14.97	15.88	16.55	18.04	

Appendix 12 – Test for normality using Shapiro-Wilk (8 stages) by gender

Tooth	Gender	p value of tds						
		A	B	C	D	E	F	G
UL1	Males			0.33	0.41	0.75	0.75	0.17
	Females				0.97	*<0.0001*	0.19	0.47
UL2	Males			*0.005*	0.30	0.45	*<0.0001*	0.43
	Females		0.28	0.22	0.88	0.88	0.12	0.19
UL3	Males			0.48	0.26	0.24	0.85	0.52
	Females			0.41	0.76	0.61	*0.01*	*0.03*
UL4	Males		0.40	0.07	0.64	0.91	0.05	0.79
	Females		0.27	0.40	0.39	*0.04*	0.33	0.39
UL5	Males	0.14	0.16	0.13	0.34	0.74	0.56	0.59
	Females	0.99	0.90	*0.002*	0.13	*0.002*	0.09	0.26
UL6	Males				0.23	*0.02*	0.14	*0.001*
	Females				0.47	0.91	0.43	0.88
UL7	Males	0.18	0.06	0.53	0.53	0.50	0.99	0.36
	Females		0.56	*0.0008*	*0.0001*	*0.002*	0.20	0.25
UL8	Males	0.65	*0.02*	0.07	0.12	*0.000*	*0.005*	*0.000*
	Females	*0.03*	0.32	*0.0004*	*<0.0001*	*<0.0001*	*0.00001*	*0.04*
UR8	Males	0.26	*0.04*	*0.02*	0.28	*0.000*	*0.02*	*0.000*
	Females	*0.04*	0.69	*0.002*	*0.0005*	*0.0002*	*<0.0001*	*0.0003*
LL1	Males			0	*0.03*	*0.02*	0.09	0.31
	Females			0.11	0.64	0.79	0.21	0.57
LL2	Males			0	0.11	*0.01*	0.60	*0.002*
	Females			0.11	0.36	0.62	0.25	0.65
LL3	Males			0.23	0.19	0.17	0.05	0.17
	Females			0.77	0.81	*0.01*	0.76	0.19
LL4	Males		0.86	0.35	0.41	0.55	*0.04*	0.48
	Females		0.42	0.45	0.93	*0.01*	*0.0005*	0.27
LL5	Males	*<0.0001*	0.45	0.09	*0.01*	0.12	0.25	0.91
	Females	0.29	0.29	*0.002*	*<0.0001*	*<0.0001*	*0.03*	0.14
LL6	Males				0.33	0.25	*0.004*	*<0.0001*

	Females				0.94	0.51	0.20	0.55
LL7	Males	0.89	*0.0002*	0.31	*0.004*	0.55	0.91	0.25
	Females		0.48	*0.04*	0.33	0.16	*0.003*	*0.0003*
LL8	Males	*0.04*	0.15	0.10	0.27	*<0.0001*	*0.02*	*<0.0001*
	Females	0.24	0.08	0.08	*0.0004*	*<0.0001*	*<0.0001*	*<0.0001*
LR8	Males	*0.0004*	0.17	0.16	0.24	*<0.0001*	*0.0009*	*0.0002*
	Females	0.12	0.41	*0.02*	*0.003*	*<0.0001*	*<0.0001*	*<0.0001*

(significant results in italics, empty cells indicate value not available)

Appendix 13 – UPPER teeth compared by Ethnic group, using 8 stages (Males)

Tooth UL1 N=145	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	3	4.4	1.2	1	5.6	-	0			0			0			0			0		
D	12	5.1	0.9	2	4.3	1.0	1	5.1	-	2	4.4	1.0	0			0			1	5.8	-
E	17	6.1	1.2	0			3	5.2	0.6	2	6.2	0.0	0			0			3	6.4	1.0
F	28	7.8	1.2	2	7.7	0.4	3	5.9	1.1	1	5.4	-	1	7.1	-	2	6.2	2.1	2	7.5	0.1
G	34	8.9	1.5	1	11.4	-	5	8.4	1.0	5	8.6	1.2	1	9.1	-	0			7	8.9	1.3

Tooth UL2 N=164	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	1	3.4	-	0			0			0			0			0			0		
C	10	5.6	1.8	2	4.6	1.4	1	5.1	-	1	5.2	-	0			0			0		
D	14	5.6	1.5	1	5.0	-	2	5.6	0.1	4	5.9	1.5	0			0			4	6.2	0.9
E	16	6.8	1.2	0			5	5.2	0.4	1	5.4	-	1	7.1	-	2	6.2	2.1	1	7.4	-
F	39	8.3	1.8	1	7.4	-	5	7.8	0.7	3	8.0	0.7	1	9.1	-	0			7	9.0	1.4
G	25	9.5	1.6	4	10.2	1.4	2	10.8	1.4	3	9.7	1.3	0			3	9.9	1.9	5	9.2	1.1

Tooth UL3 N=253	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	11	5.0	1.0	1	3.6	-	2	5.4	0.4	2	4.4	1.0	0			0			1	5.2	-
D	25	6.3	1.7	2	7.2	1.0	7	6.3	1.4	2	6.7	0.7	0			0			5	7.3	1.3
E	46	7.7	1.2	2	6.5	1.3	5	7.0	1.6	6	7.4	1.4	1	7.1	-	2	6.2	2.1	4	8.5	0.8
F	36	9.7	1.7	6	10.3	1.1	3	8.7	1.5	4	9.6	1.0	1	9.1	-	3	9.9	1.9	11	10.2	1.4
G	42	12.1	1.3	5	12.1	1.6	7	11.6	1.8	5	11.7	1.9	0			0			6	12.9	2.1

Tooth UL4 N=234	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	3	3.9	0.5	1	3.6	-	2	5.6	0.2	0			0			0			0		
C	16	4.7	0.6	1	5.6	-	5	5.2	0.4	3	5.4	1.8	0			0			3	6.0	0.9
D	49	7.6	1.2	3	7.3	0.7	5	7.3	1.1	6	7.1	1.4	0			2	6.2	2.1	5	7.9	1.0
E	28	8.3	1.3	1	8.3	-	3	7.9	0.7	3	8.9	1.2	1	7.1	-	3	9.9	1.9	6	9.0	0.8
F	24	10.7	1.6	5	10.7	0.5	3	9.4	0.4	2	10.8	0.4	1	9.1	-	0			4	10.7	0.8
G	25	12.2	1.4	5	12.1	1.6	5	11.8	1.4	6	12.8	2.3	0			0			5	12.3	1.2

Tooth UL5 N=252	ETHNIC GROUPS																				
TDS	White			Mixed			Asian			Black			Chinese			Other			Unknown		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	2	3.7	0.4	1	3.6	-	1	5.7	-	0			0			0			0		
B	5	4.7	0.7	0			1	5.5	-	1	3.7	-	0			0			0		
C	14	5.0	0.7	1	5.6	-	5	5.1	0.4	2	6.2	1.4	0			0			4	6.2	0.9
D	54	7.8	1.10	3	7.3	0.7	3	7.1	1.5	7	7.3	1.3	1	7.1	-	3	6.7	1.7	6	8.5	0.9
E	31	9.2	1.4	1	8.3	-	5	8.5	1.0	4	10.1	1.3	0			2	11.1	0.3	7	9.7	1.5
F	24	11.1	1.7	5	10.7	0.5	1	9.3	-	3	11.3	2.5	1	9.1	-	0			4	10.8	0.9
G	30	12.5	1.2	3	11.4	1.2	7	12.3	1.4	5	13.8	2.8	1	12.4	-	0			4	12.7	1.4

Tooth UL6 N=158	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	0			0			0			0			0			0			0		
D	10	4.2	0.6	2	3.7	0.3	1	4.5	-	2	4.4	1.0	0			0			1	5.2	-
E	15	5.3	0.8	1	5.6	-	4	5.	0.3	2	7.5	1.8	0			0			2	6.4	0.8
F	12	6.5	0.8	1	6.5	-	3	6.3	1.5	2	5.8	0.6	0			0			1	7.0	-
G	67	8.4	1.4	2	9.7	2.5	8	7.7	1.3	2	8.3	1.1	2	8.1	1.4	3	6.7	1.7	11	8.7	1.1

Tooth UL7 N=323	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			1	5.7	-	0			0			0			0		
B	13	4.8	0.7				2	5.0	0.7	3	4.8	0.9	0			0			1	5.8	-
C	17	6.3	1.4	2	6.0	0.7	5	5.8	0.8	2	8.0	1.1	0			0			2	6.1	1.3
D	59	7.9	1.1	2	7.7	0.4	5	7.4	1.3	3	7.4	1.2	1	7.1	-	3	6.7	1.7	9	8.1	0.9
E	31	9.9	1.5	4	10.3	1.4	5	8.7	1.1	6	8.9	1.7	1	9.1	-	2	11.1	0.3	9	10.4	1.5
F	20	11.5	1.2	7	11.6	1.6	4	12.1	1.5	2	11.9	3.4	1	12.4	-	0			3	10.9	1.2
G	60	13.9	1.3	2	16.0	1.1	3	12.6	1.7	18	14.5	1.7	0			1	15.8	-	15	14.7	2.1

Tooth UL8 N=831	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	2	8.3	0.7	1	10.2	-	1	8.5	-	0			0			0			0		
B	22	10.7	1.9	4	10.2	1.4	0			1	8.2	-	0			0			6	10.0	1.1
C	25	12.9	2.6	6	12.5	2.1	5	9.8	0.7	6	11.7	2.4	0			0			9	13.1	2.9
D	137	14.3	1.6	10	15.2	1.6	7	13.9	1.7	26	14.9	1.2	1	7.1	-	3	6.6	1.7	19	15.0	2.3
E	139	15.0	1.2	16	15.9	0.7	7	14.1	3.7	30	15.5	0.9	1	9.1	-	2	11.0	0.3	24	16.4	2.8
F	133	16.0	1.1	10	16.6	0.6	4	15.5	0.7	37	15.5	0.6	1	12.4	-	0			9	17.1	2.0
G	92	17.4	1.3	4	16.1	0.8	0			10	16.2	0.6	0			1	15.7	-	22	18.1	2.3

Tooth UR8 N=820	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	5	9.3	1.3	1	10.2	-	1	8.5	-	0			0			1	10.8	-	0		
B	17	10.2	2.2	4	10.9	2.6	1	9.2	-	1	8.2	-	0			1	11.2	-	8	10.4	2.0
C	31	12.7	2.5	5	12.2	2.0	5	10.7	1.8	5	12.1	3.4	0			0			8	12.9	3.1
D	125	14.2	1.6	12	15.3	1.4	5	13.6	1.9	29	14.7	1.3	1	16.6	-	1	15.7	-	16	14.3	1.8
E	131	15.0	1.1	16	16.0	0.7	7	14.1	3.7	29	15.6	0.7	0			3	15.9	0.9	26	16.1	1.7
F	133	15.9	1.1	12	16.7	0.5	4	15.5	0.6	37	15.5	0.6	0			0			11	17.0	1.8
G	92	17.3	1.2	2	15.4	0.7	0			12	16.3	0.6	0			0			22	18.5	2.2

Appendix 14– LOWER teeth compared by Ethnic group, using 8 stages (Males)

Tooth LL1 N=92	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			1	5.5	-	0			0			0			0		
C	1	3.4	-	0			0			0			0			0			0		
D	8	4.6	0.7	1	3.5	-	2	5.3	0.2	1	5.1	-	0			0			0		
E	7	5.0	0.5	0			3	5.2	0.6	0			0			0			1	5.8	-
F	15	6.0	1.2	2	7.2	0.9	3	5.3	0.2	1	5.3	-	0			0			3	6.4	1.0
G	31	7.8	0.9	0			4	7.5	0.6	3	8.3	1.8	1	7.0	-	1	4.6	-	3	7.3	0.2

Tooth LL2 N=145	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	1	3.4	-	0						0			0			0			0		
C	0			0			2	5.3	0.2	0			0			0			0		
D	13	4.8	0.8	1	3.5	-	1	5.7	-	3	5.0	1.2	0			0			1	5.8	-
E	11	5.1	0.6	2	6.7	1.6	5	5.2	0.4	1	5.3	-	0			1	4.6	-	2	6.1	1.2
F	25	7.4	1.1	1	6.5	-	5	7.7	0.8	1	7.2	-	1	7.0	-	0			3	7.5	0.6
G	43	8.5	1.3	3	8.6	1.4	5	9.3	1.5	4	8.6	1.3	1	9.1	-	2	7.6	0.0	7	8.8	1.3

Tooth LL3 N=248	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	1	5.4	-	0						0			0			0			0		
C	5	4.4	0.8	1	3.5	-	1	5.1	-	1	5.1	-	0			0			0		
D	22	6.1	1.7	2	7.2	0.9	7	6.3	1.3	2	4.9	1.8	0			0			5	6.9	1.6
E	49	7.4	1.4	1	5.5	-	4	6.0	1.3	5	7.2	1.4	1	7.0	-	3	6.6	1.7	7	8.1	0.8
F	45	9.5	1.5	6	9.6	1.4	5	8.8	1.4	7	9.2	1.3	1	9.1	-	0			10	10.1	1.2
G	36	12.2	1.2	4	11.0	0.4	7	11.4	1.9	5	12.2	1.9	0			1	11.2	-	4	12.5	0.6

Tooth LL4 N=253	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	4	3.9	0.4	1	3.5	-	0			0			0			0			0		
C	16	4.7	0.6	2	5.2	1.8	5	5.2	0.4	3	5.0	1.2	0			0			3	6.0	0.9
D	36	7.3	1.2	2	6.7	1.6	6	6.5	1.3	5	7.0	1.2	0			2	6.1	2.1	5	7.5	0.7
E	44	8.2	1.2	2	8.8	2.0	3	7.8	0.7	3	8.3	0.2	1	7.0	-	1	7.6	-	9	9.4	0.9
F	25	10.8	1.7	3	9.8	1.4	4	9.0	0.7	6	11.2	2.1	1	9.1	-	2	11.0	0.3	5	10.6	1.6
G	32	12.0	1.4	7	11.7	1.4	4	11.1	1.0	6	13.1	1.8	0			0			5	12.2	0.9

Tooth LL5 N=292	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	7	4.5	1.5	2	3.7	0.2	0			1	3.7	-	0			0			0		
B	4	4.6	0.7	0			0			1	5.1	-	0			0			0		
C	16	5.1	0.9	2	6.0	0.6	4	5.1	0.4	2	7.5	1.8	0			0			4	6.2	0.9
D	45	7.8	1.4	1	7.9	-	6	6.6	1.4	6	7.1	1.2	1	7.0	-	4	7.7	2.5	7	8.6	1.0
E	35	9.1	1.5	1	7.3	-	3	7.8	0.7	2	10.6	0.5	0			1	11.2	-	6	9.2	1.2
F	33	12.0	1.9	8	11.7	2.2	5	10.2	1.4	8	12.4	3.0	1	9.1	-	0			9	12.1	1.5
G	47	12.9	1.3	3	10.9	0.4	6	13.1	1.9	10	14.3	1.9	1	12.4		0			3	14.3	1.6

Tooth LL6 N=159	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	0			0			0			0			0			0			0		
D	5	4.6	0.8	2	3.7	0.2	0			1	5.1	-	0			0			0		
E	19	5.0	0.8	1	5.5	-	4	5.2	0.5	1	3.7	-	0						2	5.5	0.4
F	15	6.7	1.6	1	6.5	-	5	6.2	1.2	4	6.6	1.4	0			0			2	7.0	0.0
G	65	8.3	1.3	3	9.2	1.9	7	7.8	1.3	5	7.9	0.6	2	8.0	1.4	3	6.6	1.7	12	8.6	1.0

Tooth LL7 N=387	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	2	4.6	0.3	1	3.9	-	0			0			0			0			0		
B	16	5.1	1.5	0			3	5.2	0.6	4	5.7	2.1	0			0			0		
C	16	6.1	1.1	2	6.0	0.6	6	5.6	0.7	2	6.7	0.6	0			0			5	6.5	0.9
D	47	7.7	1.1	2	7.6	0.3	5	7.7	0.5	3	7.3	1.1	1	7.0	-	3	6.6	1.7	3	8.0	0.9
E	35	9.3	1.4	3	9.9	1.5	4	9.1	0.5	4	9.4	1.4	1	9.1	-	2	11.0	0.3	12	9.9	1.5
F	31	11.8	1.5	7	11.5	1.5	4	12.2	1.3	5	11.9	2.7	1	12.4	-	0			4	11.3	0.9
G	99	13.9	1.2	3	14.3	3.0	4	13.1	2.0	29	14.8	1.1	0			0			18	14.5	1.6

Tooth LL8 N=837	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	17	10.2	2.3	4	10.0	1.2	1	8.5	-	3	13.4	4.5	1	12.4	-	0			3	9.4	3.2
B	19	11.7	2.4	4	12.4	1.8	4	9.7	0.7	4	10.5	2.5	0			0			14	11.0	1.9
C	47	13.7	1.5	4	13.0	2.9	3	11.5	1.1	7	11.6	2.1	0			1	11.2	-	5	14.8	1.8
D	118	14.3	1.4	3	14.0	2.6	6	14.4	1.4	15	14.7	1.1	0			1	15.7	-	6	14.5	2.4
E	141	15.2	1.1	17	15.7	0.6	4	13.6	5.0	32	15.6	0.7	2	16.3	0.4	1	15.7	-	21	15.6	1.3
F	130	16.5	1.1	14	16.3	0.8	6	15.6	0.5	45	15.5	0.8	0			2	16.0	1.3	19	16.9	1.9
G	73	17.7	1.5	4	16.5	0.4	0			10	16.2	0.6	0			0			26	17.8	1.6

Tooth LR8 N=837	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	22	10.4	2.3	2	9.2	1.3	0			2	9.6	1.9	0			0			2	7.6	0.8
B	18	11.6	1.9	3	11.7	0.9	4	9.7	0.7	3	10.9	3.1	1	12.4	-	1	11.2	-	13	10.8	2.0
C	38	13.4	1.6	4	13.0	2.9	3	11.5	1.1	6	11.8	2.2	0			0			4	15.1	1.8
D	120	14.3	1.4	7	15.2	1.9	5	13.8	0.7	11	14.0	1.6	0			1	15.7	-	9	14.7	2.3
E	153	15.4	1.2	15	15.8	0.7	5	14.3	4.6	34	15.6	0.6	2	16.3	0.4	3	15.9	0.9	20	15.5	1.3
F	127	16.4	1.1	16	16.2	0.6	6	15.6	0.5	46	15.6	0.8	0			0			22	17.1	1.9
G	73	17.7	1.4	2	16.3	0.5	0			10	16.2	0.6	0			0			24	17.7	1.3

Appendix 15 – UPPER teeth compared by Ethnic group, using 8 stages (Females)

Tooth UL1 N=103	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	2	1.9	0.2	0			0			0			0			0			0		
C	0			0			1	3.0	-	0			0			00			0		
D	10	5.1	0.9	0			0			2	3.8	1.1	0			1	4.7	-	0		
E	11	5.9	0.9	1	5.4	-	4	5.0	1.0	0			0			0			2	7.7	0.6
F	12	6.9	1.0	3	6.5	0.4	2	7.4	1.5	0			2	7.6	0.7	0			3	7.8	1.5
G	31	8.3	1.3	3	10.7	0.7	6	8.2	1.0	3	8.9	1.3	1	8.60	-	0			2	8.6	0.1

Tooth UL2 N=130	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	3	2.6	1.0	0			0			0			0			0			0		
C	2	4.8	1.2	0			1	3.0	-	1	3.0	-	0			0			0		
D	11	5.6	0.8	1	5.4	-	2	4.9	1.8	1	4.6	-	0			0			3	6.9	1.4
E	14	6.6	1.2	1	8.2	-	4	6.3	1.7	0			1	8.1	-	0			1	9.5	-
F	24	7.6	1.2	3	6.5	0.4	4	7.9	1.0	3	8.9	1.3	1	7.2	-	1	8.0	-	4	7.9	1.0
G	27	9.3	1.2	5	10.0	1.2	4	9.8	2.4	4	9.8	1.4	1	8.6	-	0			3	9.1	0.5

Tooth UL3 N=203	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			1	3.0	-	0			0			0		
C	4	4.5	0.7	2	4.2	1.6	1	3.0	-	0			0			1	4.7	-	0		
D	15	6.1	1.1	0			2	4.9	1.8	2	4.8	0.3	0			0			4	7.5	1.7
E	24	6.9	1.1	4	6.9	0.9	6	7.4	1.5	0			3	8.0	0.7	0			3	7.5	1.0
F	44	8.9	1.0	3	9.2	0.6	6	9.4	2.2	6	9.3	1.5	0			1	8.0	-	5	9.7	1.5
G	49	11.6	1.6	3	10.9	0.5	4	11.1	0.4	7	10.9	1.0	0			1	13.6	-	2	9.6	1.2

Tooth UL4 N=182	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			2	4.2	1.6	0			1	5.0	-	0			0			0		
C	10	5.0	0.8	0			4	4.8	1.1	1	4.6	-	0			0			0		
D	33	7.1	1.1	3	7.0	1.1	3	7.3	1.2	0			3	8.0	0.7	1	8.0	-	7	7.6	1.3
E	28	8.6	1.3	4	8.6	1.3	3	8.3	1.5	4	8.7	1.1	0			0			3	9.2	0.3
F	28	9.9	1.3	1	11.3	-	1	8.8	-	2	9.7	0.2	0			0			3	10.5	1.9
G	21	12.3	1.6	2	10.7	0.4	6	11.2	1.2	6	12.1	2.1	0			0			2	10.2	2.1

Tooth UL5 N=209	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	2	3.6	0.2	0			1	4.2	-	1	3.0	-	0			0			0		
B	1	4.4	-	1	5.4	-	3	4.0	2.0	1	5.0	-	0			0			0		
C	10	6.1	1.7	1	6.0	-	1	5.2	-	1	4.6	-	0			0			1	5.4	-
D	32	7.4	1.1	4	8.8	1.9	5	7.5	1.0	0			3	8.0	0.7	1	8.0	-	6	7.9	1.1
E	35	9.1	1.8	3	8.5	1.6	3	9.1	1.2	5	8.9	1.1	0			0			3	9.2	0.3
F	25	10.7	1.5	0			4	11.2	1.8	5	11.1	1.7	0			0			4	9.8	1.5
G	37	12.6	1.4	2	10.7	0.4	2	10.8	0.3	5	13.6	2.1	0			0			1	12.1	-

Tooth UL6 N=119	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	1	3.5	-	0			0			0			0			0			0		
D	3	4.8	1.7	2	3.8	1.0	4	3.3	0.8	2	4.0	1.4	0			1	4.7	-	0		
E	10	5.4	0.7	1	5.4	-	1	5.2	-	1	4.6	-	0			0			1	5.4	-
F	9	6.4	0.8	0			2	6.6	0.6	0			0			0			1	8.1	-
G	53	8.0	1.3	7	7.9	1.4	5	7.9	1.1	3	8.9	1.3	3	8.0	0.7	1	8.0	-	8	8.6	1.4

Tooth UL7 N=287	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			2	3.8	1.1	0			0			0		
B	7	4.6	0.7	1	4.6	-	2	3.0	1.0	1	5.0	-	0			0			0		
C	8	6.3	1.5	2	5.7	0.5	2	5.7	0.7	0			0			0			2	7.1	0.3
D	53	7.8	1.3	4	7.9	1.5	6	7.5	0.9	4	10.5	3.4	3	8.0	0.7	1	8.0	-	8	8.2	1.4
E	32	9.6	1.2	3	9.7	1.4	7	10.7	1.5	3	11.3	4.1	0			0			0		
F	13	11.7	1.4	1	10.4	-	2	10.0	1.6	5	11.7	2.4	0			0			1	10.4	-
G	70	13.2	1.9	3	14.2	2.8	1	15.3	-	30	14.6	1.8	0			1	13.6	-	9	12.1	2.0

Tooth UL8 N=1039	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	10	9.3	1.8	0			0			0			0			0			0		
B	16	11.3	2.5	1	8.7	-	2	9.7	1.3	2	11.6	5.1	0			0			2	10.2	2.1
C	28	13.4	2.4	6	13.8	2.6	2	10.3	1.1	11	13.1	2.5	0			2	15.0	1.96	4	12.1	2.8
D	190	14.4	1.7	14	15.5	0.6	6	15.8	0.5	43	15.0	1.5	0			1	16.2	-	12	13.7	2.7
E	200	15.0	1.4	13	15.8	0.5	6	15.3	0.8	36	15.8	1.0	1	15.2	-	2	15.7	0.94	9	17.8	1.9
F	193	16.2	1.3	19	15.9	0.6	2	14.2	4.4	42	15.8	0.9	0			2	16.1	0.96	3	16.1	0.4
G	124	17.7	1.2	4	16.2	0.5	1	22.6	-	24	16.3	0.9	0			0			6	18.3	1.7

Tooth UR8 N=1032	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	8	9.3	2.0	0			0			0			0			0			0		
B	19	11.5	2.2	1	8.8	-	2	9.7	1.3	2	9.3	1.7	0			0			2	10.2	2.1
C	33	13.3	2.6	4	12.7	2.5	3	11.9	2.8	9	13.2	2.6	0			1	13.6	-	5	12.9	3.1
D	194	14.4	1.8	15	15.5	0.5	5	15.5	0.4	44	15.2	1.4	0			2	16.3	0.1	10	13.1	2.4
E	188	15.0	1.4	13	15.7	0.6	6	15.5	0.8	32	15.5	1.1	1	15.2	-	2	15.7	0.9	12	17.7	1.7
F	188	16.3	1.3	20	16.1	0.6	2	14.2	4.4	43	15.9	1.0	0			2	16.1	1.0	4	16.0	0.4
G	127	17.6	1.3	4	16.2	0.5	1	22.6	-	25	16.4	0.9	0			0			3	19.0	1.2

Appendix 16 – LOWER teeth compared by Ethnic group, using 8 stages (Females)

Tooth LL1 N=74	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	1	3.5	-	0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	1	4.0	-	0			1	3.0	-	1	3.0	-	0			0			0		
D	2	3.6	0.2	1	3.1	-	0			0			0			1	4.7	-	0		
E	7	5.4	0.7	0			2	5.0	1.9	2	4.8	0.3	0			0			0		
F	10	5.9	0.8	1	5.4	-	2	5.7	0.7	0			1	7.2	-	0			0		
G	29	7.6	1.2	4	7.4	1.8	3	8.1	1.0	1	7.4	-	1	8.1	-	0			3	8.3	1.2

Tooth LL2 N=103	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	1	4.0	-	0			1	3.0	-	1	3.0	-	0			0			0		
D	7	5.0	1.2	1	3.1	-	1	3.6	-	0			0			0			0		
E	6	5.5	0.7	1	5.4	-	2	5.7	0.7	2	4.8	0.3	0			0			0		
F	16	6.8	1.2	2	7.5	1.0	1	6.3	-	0			2	7.6	0.7	0			3	6.9	1.4
G	40	8.2	1.2	4	8.4	2.4	4	8.0	0.8	3	8.9	1.3	0			1	8.0	-	4	8.0	1.3

Tooth LL3 N=187	ETHNIC GROUPS																				
TDS	White			Mixed			Asian			Black			Chinese			Other			Unknown		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			1	3.1	-	0			1	3.0	-	0			0			0		
C	2	3.8	0.5	1	5.4	-	1	3.0	-	0			0			0			0		
D	13	5.7	1.2	0			3	5.0	1.3	2	4.8	0.3	0			1	4.7	-	1	5.4	-
E	23	6.7	1.5	3	7.6	2.1	2	7.7	1.1	1	7.4	-	1	7.2	-	0			5	8.1	1.0
F	49	8.7	1.0	4	8.2	1.0	7	8.5	1.3	5	9.4	0.8	2	8.4	0.4	1	8.0	-	4	8.6	1.2
G	34	11.2	1.4	4	11.9	2.1	6	10.9	1.8	6	11.3	1.6	0			0			4	10.1	1.7

Tooth LL4 N=201	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			1	3.1	-	0			1	3.0	-	0			0			0		
B	2	4.2	1.1	0			2	3.3	0.5	0			0			0			0		
C	8	5.0	1.0	1	5.4	-	2	4.1	2.7	0			0			1	4.7	-	0		
D	26	6.8	1.1	2	7.4	2.0	3	5.2	1.1	3	5.7	1.5	1	8.6	-	1	8.0	-	6	7.4	1.4
E	32	8.1	1.2	4	8.5	1.3	4	9.0	0.7	5	9.4	0.8	2	7.6	0.7	0			3	9.2	0.4
F	36	10.0	1.3	2	9.0	3.2	5	8.0	1.1	6	13.4	3.1	0			0			4	10.1	1.8
G	24	11.5	1.3	2	10.7	0.4	5	11.5	1.0	5	13.2	2.3	0			0			2	9.7	1.4

Tooth LL5 N=254	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			1	3.6	-	0			0			0			0		
B	2	5.2	1.1	1	5.4	-	2	4.2	2.7	0			0			1	4.7	-	0		
C	11	5.9	1.7	1	6.0	-	2	4.7	0.7	2	4.8	0.3	0			0			1	5.4	-
D	28	7.1	0.9	4	9.9	4.1	4	8.0	1.6	1	7.4	-	3	8.0	0.7	1	8.0	-	6	8.0	1.2
E	34	8.9	1.6	2	8.4	2.3	3	8.4	1.2	7	10.8	2.9	0			0			2	9.1	0.6
F	38	11.3	2.0	1	10.4	-	5	10.5	2.2	5	11.9	2.5	0			0			8	10.5	1.6
G	62	12.6	1.2	2	13.0	2.8	2	10.8	0.3	12	13.8	1.7	0			0			0		

Tooth LL6 N=120	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			0			0			0			0			0			0		
B	0			0			0			0			0			0			0		
C	0			0			0			0			0			0			0		
D	2	3.9	0.1	1	3.1	-	3	3.0	0.7	1	3.0	-	0			1	4.7	-	0		
E	8	5.4	0.9	2	5.0	0.6	1	4.2	-	2	4.8	0.3	0			0			0		
F	12	6.3	0.7	0			2	6.1	1.2	0			0			0			1	5.4	-
G	56	8.1	1.2	7	7.9	1.4	6	7.6	1.2	3	8.9	1.3	3	8.0	0.7	1	8.0	-	8	8.3	1.1

Tooth LL7 N=355	**ETHNIC GROUPS**																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	0			1	3.1	-	0			1	3.0	-	0			0			0		
B	8	4.8	0.8	1	4.6	-	1	3.6	-	1	4.6	-	0			1	4.7	-	0		
C	10	6.0	0.7	2	5.7	0.5	4	4.5	1.7	1	5.0	-	0			0			2	6.3	1.3
D	41	7.6	1.2	4	7.9	1.5	7	7.7	1.0	1	7.4	-	3	8.0	0.7	1	8.0	-	5	8.0	1.1
E	35	9.6	1.2	3	9.7	1.4	6	10.3	1.0	5	9.5	0.8	0			0			2	9.0	0.7
F	25	11.2	1.6	2	12.7	3.3	2	12.2	1.5	8	11.9	2.3	0			0			4	10.2	1.8
G	116	13.7	1.6	9	15.3	1.7	1	15.3	-	32	14.9	1.1	0			2	14.3	0.97	8	12.8	1.8

Tooth LL8 N=1052	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	11	10.4	2.9	1	6.8	-	0			1	10.5	-	0			0			0		
B	27	12.0	2.3	1	15.0	-	5	10.3	1.0	3	9.9	1.9	0			0			2	9.7	1.1
C	68	13.9	2.0	4	14.3	2.6	2	12.3	3.9	6	13.3	2.8	0			0			3	13.7	3.7
D	203	14.6	1.6	8	14.6	1.7	7	15.4	0.6	32	14.9	1.3	0			2	16.3	0.1	7	13.9	4.1
E	183	15.5	1.4	16	15.7	0.5	5	15.8	0.8	44	15.7	1.2	1	15.2	-	2	15.7	0.9	11	16.9	2.6
F	167	16.8	1.6	19	16.0	0.6	6	15.3	5.1	49	15.8	0.9	0			2	16.1	1.0	5	16.9	1.6
G	104	18.1	1.6	7	16.0	0.5	0			30	16.4	0.8	0			2	16.3	0.7	6	19.0	1.4

Tooth LR8 N=1043	ETHNIC GROUPS																				
TDS	**White**			**Mixed**			**Asian**			**Black**			**Chinese**			**Other**			**Unknown**		
	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD	n-tds	mean	SD
A	14	10.6	2.6	1	6.8	-	0			2	9.3	1.7	0			1	13.6	-	0		
B	23	12.0	2.3	1	11.3	-	5	10.3	0.9	1	11.7	-	0			0			3	11.5	0.99
C	67	13.9	1.8	5	14.4	2.3	2	12.3	3.9	8	13.1	2.7	0			1	16.4	-	2	12.5	4.23
D	198	14.6	1.6	8	15.1	1.8	8	15.5	0.7	31	15.0	1.4	0			1	16.2	-	9	14.5	3.58
E	175	15.6	1.5	18	15.6	0.5	4	15.5	0.5	46	15.6	1.1	1	15.2	-	2	15.7	0.9	9	16.5	2.34
F	165	16.5	1.5	19	15.9	0.6	6	15.3	5.2	51	15.9	0.9	0			2	16.0	0.9	4	16.0	0.35
G	108	18.2	1.5	8	16.0	0.5	0			26	16.4	0.8	0			2	16.3	0.7	6	18.5	2.13