Dental Development in a UK population:

Does Ethnicity Matter?

Dental Development in a UK population

of White British and Black British or Other Black Ethnicity

This thesis is submitted for the Degree of Doctor of Philosophy

in

October 2020

by

Sally Elizabeth Gallia

Supervisor:

Professor Fiona Gilbert FRCR FRCP(G) FRCP(E)

Department of Radiology

University of Cambridge

Lucy Cavendish College

Declaration

I, Sally Elizabeth Gallia née Andrews, declare that this thesis is the result of my own work and includes nothing which is the outcome of work done in collaboration except as declared and specified in the text. It is not substantially the same as any that I have submitted, or, is being concurrently submitted for a degree or diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared and specified in the text. I further state that no substantial part of my thesis has already been submitted, or, is being concurrently submitted for any such degree, diploma or other qualification at the University of Cambridge or any other University or similar institution except as declared and specified in the text. It does not exceed the prescribed word limit for the Clinical Medicine Degree Committee.

Acknowledgements

I would like to acknowledge the wise and wonderful people who have made this study possible. Firstly, I thank my Supervisor, Professor Fiona Gilbert, for her much appreciated understanding, support, advice, and encouragement. Dr Pat Set has also always been an invaluable guide and I am truly grateful for her kindness and support.

I owe a sincere debt of gratitude to Professor Fraser McDonald at Guy's Hospital without whom I could not have carried out this project. I would also like to thank Professor Graham Roberts for introducing me to dental age estimation, sharing his knowledge and DARLInG system of data collection, and for leading me to investigate this subject in greater depth. I am also very grateful to Mrs Fiona Warburton for all her valuable advice and support.

I would like to thank the King's College Dental Institute Orthodontics team and many staff at Guy's Hospital for their help, friendship, and good humour. I also thank those at Addenbrooke's Hospital and Lucy Cavendish College, and all my friends and colleagues, who have encouraged and facilitated my progress. I acknowledge the contribution of my children, particularly Steph for her remarkable wisdom, Will for his invaluable tutorials and incredible patience, and Zand for his philosophical support throughout. Thank you with all my heart.

Abstract

The aim of this study was to compare third molar development in a London population of self-assigned Black British or other Black ethnicity (the Black British group) with that of self-assigned White British subjects. The significance of population differences in dental age estimation (DAE) in these groups has been debated but not previously studied in the UK.

This thesis reviews the literature associated with the maturation of children and young adults, the techniques and challenges associated with age estimation and establishing the 18-year-old threshold, and the evidence for and significance of ethnic variability in dental development.

Data was collected from dental panoramic tomographs (DPTs) of 5,590 subjects aged 6.00 - 23.99 years: 3,555 White British and 2,035 Black British, aiming for 50 male and 50 female subjects in each 6-monthly age band. At every Demirjian stage (TDS) A-H of all third molars, subjects of Black ancestry were younger compared to those of White ancestry with mean ages for males and females generally at least one year and 1.5 years apart respectively. For the lower left third molar the mean ages at TDS A-H, in both males and females, were highly significantly different ($p<0.001$). Wide age ranges were seen for all third molar TDS in both ethnic groups. In 17-year-old males, 75% of the Black British group and 43% of the White British group had lower left third molars at TDS G or H. In 18-year-old males, these figures were 88% and 61% respectively. Hypodontia, with or without third molar agenesis (TMA), was approximately twice as likely in the White British group compared to the Black British group, and TMA only was approximately three times as likely. Developmentally missing teeth were shown to be associated with delayed third molar development.

These findings confirm the variability of third molar development, the limitations of DAE for determining the 18-year-old threshold, and the important significance of ethnicity in DAE.

Sally E Gallia (Andrews). Dental Development in a UK population: Does Ethnicity Matter?

Contents

List of Tables

List of Figures

List of Abbreviations

BDA	British Dental Association
DAE	Dental Age Estimation
DARLInG	Dental Age Research London Information Group
DOB	Date of Birth
DOR	Date of Radiograph
DPT	Dental Panoramic Tomograph or Dental Panoramic Radiograph
EPR	Electronic Patient Record
EU	European Union
FGDP(UK)	Faculty of General Dental Practice (UK)
GDC	General Dental Council
GSTT	Guy's and St Thomas' NHS Foundation Trust
IOFOS	International Organization for Forensic Odontostomatology
IRAS	Integrated Research Application System
IRMER	Ionising Radiation (Medical Exposure) Regulations
mDNA	Mitochondrial DNA
MMM	Mandibular Maturity Markers
MRI	Magnetic Resonance Imaging
PLV	Periodontal Ligament Visibility
RCW	Root Canal Width
RPV	Root Pulp Volume
SD	Standard Deviation
SNP	Single-nucleotide polymorphism
TDS	Tooth Development Stage
TMA	Third Molar Agenesis
UASC	Unaccompanied asylum-seeking children
UN	The United Nations
UNCRC	United Nations Convention on the Rights of the Child
UNHCR	The United Nations High Commissioner for Refugees
UNICEF	United Nations International Children's Emergency Fund
UTJ	Upper Tribunal Judge
UK	United Kingdom

Chapter 1

Introduction

1.1 The Importance of Age Estimation

A birth certificate establishes an individual's chronological age, the measurement of time elapsed from birth, which is then reinforced by family and other documentary records. Birth registration is considered an essential component of an individual's identity, a basic human right [1], which allows conformation with rules accepted by society and the receipt of age-appropriate benefits and support. Despite this, the births of nearly 25% of children under the age of 5 worldwide have never been recorded [2]. In Sub-Saharan Africa there were 95 million people without birth registration in 2017 and this figure is expected to rise to 115 million by 2030 [3].

Across the world, there is variation in the assignment of legal age limits for marriage, military service, eligibility for a driver's licence, the purchase of alcohol, and so on. In England and Wales, the ages of 10 for criminal responsibility, 16 for sexual consent with specific legal protection for children aged 12 and under [4], 13 for statutory rape [5], and 18 for adulthood are important milestones. The incorrect assignment at these thresholds of age clearly has life-changing repercussions. The problem can be immense in countries such as India where many have poorly recorded, unrecorded, or fraudulently documented births and where there are important legal age thresholds at many stages of childhood [6].
In view of the variable nature of human maturation in emotional and intellectual terms as well as physically, these threshold ages seem arbitrary [7]. The age of majority has been constantly subject to change, varies worldwide and in the US from State to State [8], and varies according to purpose, whether it be aspects of civil or criminal justice, voting, alcohol purchase, and so on. In the UK, in the year 1678, children aged 10 were legally old enough for consensual sex [9], the Children and Young Persons Act 1933 [10] raised the age of criminal

responsibility from 7 to 8 years of age, and the age of majority was 21 until 1970. The 18-year-old threshold of adulthood set by the human rights treaty, the United Nations Convention on the Rights of the Child (UNCRC) [11], is generally, but not universally, applicable at worldwide borders. The threshold of adulthood still varies between 16 and 21 years, the minimum age of criminal responsibility between 7 and 18, and other important thresholds vary considerably [5]. Whatever legal thresholds are set, the establishment of age in people without the appropriate credentials poses a challenge to border and government authorities and age estimation becomes of significant importance.

A refugee is someone who has fled his or her home and country owing to "a well-founded fear of persecution because of his/her race, religion, nationality, membership in a particular social group, or political opinion" [12]. Many are escaping the effects of natural or man-made disasters, have been displaced from their homes in their own country, or are refugees or asylum seekers who have fled to another country [13].

Currently, there are an unprecedented 25.9 million people who have been forced to flee their country with half of those being under 18 years of age [14]. Most come from Africa and 6.3 million are from sub-Saharan Africa [15]. Countries from which the largest numbers of refugees originate are, in order, the Syrian African Republic, Afghanistan, South Sudan, Myanmar, Somalia, Sudan, Democratic Republic of Congo, Central African Republic, Eritrea and Burundi [15].

An asylum seeker is defined as a person who has left their country of origin and formally applied for asylum in another country but whose application is not yet concluded [16]. In the UK, an unaccompanied asylum-seeking child (UASC) is a person under 18, applying for asylum in his or her own right, who is separated from both parents and not being cared for by an adult who by law has responsibility to do so [17]. UASC are the responsibility of the local authority and financial support, suitable accommodation, and other services such as education, until the age of 18 regardless of immigration status must be provided for them [18]. An age must be assigned to these children if there is no birth documentation available.

Asylum-seeking children of unknown age often arrive without family members to support them, while others are discovered as victims of human trafficking. The need for age estimation arises whenever a person presents without knowledge of their age or, without the necessary documentation to prove it, their age is disbelieved. While there is injustice if a

child is wrongly assessed as adult, adults may deliberately make false claims of being under 18 to take advantage of benefits to which they are not legally entitled. This may lead to problematic circumstances [19]. There are also implications for those involved with the criminal justice system as custodial arrangements differ depending on the age of the offender.

Age estimation is applied in a variety of other situations. For example, it may be used to counter attempts made by some professional sportsmen to falsify their age for personal and financial gain [20], to assess age from images in child pornography cases [21], and occasionally to assist in re-establishing the identity of an amnesic person with no memory of their personal details [22]. Age estimation is used in forensic settings to assist with identification of the deceased and provides useful information in archaeological situations. Although an age estimation with a range of several years may be helpful, an estimation deciding the attainment of an age threshold, such as 18 years, has life-changing consequences for an asylum seeker.

Age is estimated by assessing facial appearance, stature, and psychological, skeletal, and dental development. Difficulties arise with all these approaches.

1.2 Physical Characteristics

Physical development and appearance varies across the world. For example, in some parts of Afghanistan it is common to grow a beard at the age of 13 or 14 [23]. Many studies have shown that it is difficult to estimate age by looking at faces. In a study of shopkeepers and pub employees, 38% of 16 -year-old boys and 56% of 16-year-old girls were judged to be of legal drinking age, that is, at least 18 years old, and this same response was made for 3% of boys of just 13 years of age [24]. Bias exists whereby the ages of young faces are overestimated, and the age of older faces underestimated, as well as a further bias of the perceived age being affected by the age of the previous face seen [25].

Physical characteristics such as weight and height are unreliable for determining age because of genetic and other influences during life. Secondary sexual characteristics are not considered reliable indicators of chronological age [26]. These physical signs are influenced by growth in general making age determination from sexual characteristics no more certain than from stature and general appearance. Systems designed to identify stages of maturity, such as the Tanner stages of secondary sexual characteristics [27] and many of the skeletal and earlier dental development staging schemes [28, 29], are not necessarily transferable for determining chronological age.

The many factors affecting growth have been summarised in order of influence as follows: chance, genetic differences, sex, regional variation, secular trends, human ecology, climate, and age [30]. Bone development is affected by nutritional, hormonal, pathological, and environmental conditions[31]. Poor nutrition and most diseases delay development which could lead to an underestimation of age while some conditions, such as endocrine disorders which accelerate development, could lead to overestimation. The correlation between skeletal and dental development is not fully understood but dental development is subject to less variation in relation to chronological age and appears to be controlled independently [32].

As factors affecting growth have a cumulative effect, the difference between apparent age and chronological age is increasingly prone to widen as the years pass and error ranges increasing. The accuracy of age assessment therefore decreases as infancy and childhood progress into adolescence and becomes even more of a challenge in later years. This general rule applies to all age estimation methods.

Determining chronological age from the physiological signs of age is the challenge posed. Estimation of age relies on quantification of age-related biological variables, analysis of the data collected and the construction of a system which allows conversion of the results into a chronological age. Any age estimation technique is dependent on understanding the factors which affect these variables and taking them into account. The use of a reference dataset (RDS) which matches the growth characteristics of the individual being examined is clearly important and should ideally consider all factors which are responsible for growth variation in the reference population.

1.3 Skeletal Age Estimation

During the process of ossification, the shape and size of the bones change to achieve growth and development of the skeleton. In the second decade, growth of the long bones continues but at a slower rate than in the first decade of life. The ossification centres, or epiphyses, begin to fuse and the pattern in which this occurs follows a chronological sequence [33]. The times of initial fusion of the epiphyses of the long bones mostly occur during the teenage years. Many factors including gender, nutrition, endocrinology, pathology, and environmental conditions influence these changes [34]. Most diseases delay development which could lead to an underestimation of age while some, such as endocrine disorders which accelerate development, lead to overestimation. Whereas ethnicity bears a relationship with some skeletal features in terms of shape and size, with these features enabling likely ethnicity of skeletal remains to be determined by anthropologists [35], skeletal maturation has appeared not to be dependent on ethnicity but on genetically determined factors which can be influenced by environment [36, 37]. Skeletal maturation has however been found to be significantly delayed in males of Black ethnicity compared to White males in South Africa [38].

Skeletal age determination by examination of the size of single developing bones and the degree of epiphyseal fusion gives age ranges of at least two years for each epiphysis [33, 39].

For age estimations in young people, the skeletal hand and wrist is thought to be particularly suitable because development is complete around 18 years of age. A physical examination is conducted to identify any pathological features, and the radiograph is compared with standard images of the relevant age and sex using an atlas method [28, 40] or measurements of the wrist bones are taken leading to an age estimation [41, 42, 43, 44].

The Greulich and Pyle method relies on a reference data set compiled in the USA in the 1930's which questions its universal applicability and validation studies find that in several populations, e.g. Aboriginal Australians, Turkish, and Indians, there is consistent overestimation of age [45]. Using this method variation in growth and development has been claimed to have a Standard Deviation (SD) of approximately 0.6 to 1.1 years, the higher values referring to older ages with its use curtailed after fusion of the epiphyses, which occurs at an average age of 17 in girls and 18 in boys [46]. Despite reference data compiled in

the 1930's, the Greulich and Pyle method has been termed the gold standard in bone age determination, still applicable and recommended today [47]. An accuracy of around +/- 2 years in 95% of subjects results in a lack of precision impossible to reduce and with consequential limited relevance in a judicial context [47.] The Thiemann and Nitz [48], and Gilsanz and Ratib [49], atlas methods have been more recently presented. Cameriere's method of measuring the ratios associated with hand/wrist bone development was specifically designed for age estimation. In an Italian population between 5 and 17 years of age, this method showed a Standard Error of the estimate as +/- 1.19 years [41].

Although not routinely used in the UK Courts, radiological examination of the hand/wrist recommended and regularly undertaken for age estimation in countries such as Germany [50] and Italy [51] . Its use in Italy has been discontinued since 2017 for reasons that have been described as ideological controversy [52]. In Nordic countries except Iceland age estimation examination based on the Greulich and Pyle atlas was used after this time [53] and it is likely that it is still carried out. Magnetic Resonance Imaging (MRI) assessment of the hand/wrist is also advocated [54].

The medial end of the clavicle is the last epiphysis to fuse and it does so between the approximate ages of 17 and 22. If fusion is complete and an epiphyseal scar visible, then a woman is said to be at least 20 years old and a man at least 21 years old [46]. Disappearance of the scar occurs at 26 years at the earliest for both males and females [46]. Therefore, a CT scan of the medial end of the clavicle as well as a hand/wrist assessment has been considered appropriate in Germany, for example, if the young person is thought to be over 18. Claims are made for MRI examination of the clavicle as a more ethically-acceptable and valid test of age [55, 56]. In a comprehensive review of MRI and CT studies with analysis of 10 studies and a total of 4,190 subjects, left and right sides were shown to display different stages in 11% of subjects and age ranges for different stages were large [57]. Chronological age was not reliably distributed for the stages of medial clavicular development and uneven age distribution in the samples was said to influence the results. It was suggested that minimum ages for each stage, the minimal age concept, provided the most useful information for age assessment. Another review, analysing 13 articles and 5,605 subjects, stated that attainment of the 18-year-old threshold could be established if Stages 4 or 5, which both denote the completely fused epiphyses with Stage 5 having disappearance of the scar, had been reached [58]. For males, the Stage 3c was also said to be indicative of 18 years of age. Five stages, from Stage 1 with the

ossification centre not ossified to Stage 5, the end stage, have become the established staging method [59].

A skeletal age estimation method currently used routinely in Sweden is based on an MRI of the knee, the distal part of the femur [60, 61]. The changing shape of bones, such as the third cervical vertebra, around the 18-year-old threshold has also attracted research [62]. Age ranges for each stage, or set of measurements of the cervical vertebrae, have been found to be too large for accurate age estimation and sample sizes have been limited [63].

1.4 Dental Age Estimation

Tooth Formation and the Development of the Dentition

Teeth begin their formation with the establishment of tooth germs and assessment can be made of the consequent developmental stages from histological and radiographical appearance. Inside a crypt within the alveolar bone, hard tissue is first laid down at the cusp tips, as illustrated by Demirjian Stage A in Figure 1 which eventually coalesce to form a mineralised occlusal surface. The enamel-covered crown, or coronal portion, continues to form, dentine formation slightly preceding that of enamel, both being laid down in incremental layers which later remain visible microscopically, lengthening until complete when the cemento-enamel junction is reached. Then root development begins, the roots lengthening toward the apices until the root tips are completed [64], as illustrated by Demirjian Stage H in Figure 1.

Teeth start to develop at six weeks in utero. The primary or deciduous dentition emerges between about 6 and 30 months of age. From around the age of six, the primary teeth are gradually replaced by their secondary or permanent successors with the addition of the first, second and, finally, third molars [64]. The complete permanent dentition consisting of eight incisors, four canines, eight premolars, and twelve molars. According to standard textbooks,

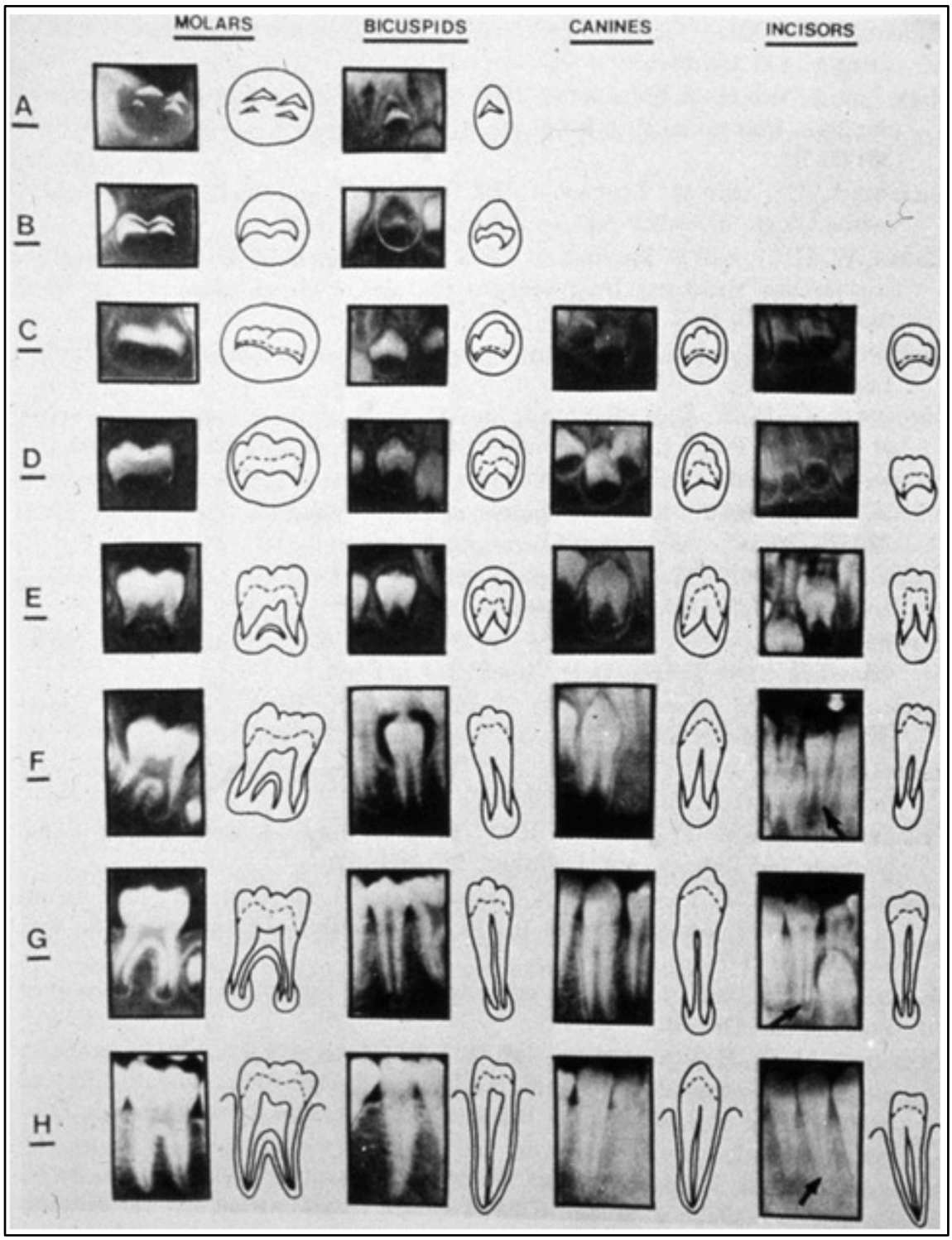


Figure 1. Demirjian's system for rating developmental stages for permanent teeth – pictorial and radiographical representations [65]. (Bicuspids is an American term for premolars). (Permission for reproduction granted by Wayne State University Press.)

the third molars appear in the mouth between 17 and 21 years of age and are complete at about 18-25 years of age [64, 66] .

A tooth is termed unerupted until clinical or gingival emergence, defined as the appearance of some portion of the tooth's crown piercing the gingival mucosa, occurs. The tooth is then partially erupted until the coronal portion has emerged completely and/or the tooth is in occlusion with an opposing tooth. It is then fully erupted. If unimpeded, teeth are said to generally emerge when the root is approximately three-quarters complete [67] or Demirjian stage F or G [68] (Figure 1). However, between one third and one half of the roots of the first molar have been shown to have formed at the time of clinical emergence [69]. The difficulty in determining the exact stage of root development at time of emergence lies in the absence of a radiograph taken at that precise time. Alveolar emergence, detected in skeletal material or radiographs, is defined as the crown piercing the alveolar bone but still not through the gingival mucosa.

The maxilla and mandible develop in tandem with the developing dentition, changing in size and shape during childhood and adolescence to accommodate the adult dentition. The development of the dentition offers information about the age of living individuals but, by the age of 16, the range in timing of dental development has been increasingly widening and generally all teeth apart from the third molars have completed their development. Permanent teeth typically erupt earlier in females than in males but for third molars this pattern is reversed. Although it is thought that there is no better biological marker of maturity than the third molar, the only tooth still developing after the age of 16, these teeth are the most variable of all teeth in terms of morphology, size, possibility of agenesis, and range in developmental timing.

In 1934, Banks examined radiographs of 1000 patients between 6 and 22 years from a Colorado orthodontic practice, most of whom had radiographs taken annually over several years [70]. Third molar cusps formed about one year after a complete crypt was seen and that each successive sixth of the tooth's development was seen to take about one year. The time for complete third molar formation varied between seven and nine years. Maxillary third molar calcification began one to two years before the mandibular third molar, but this variation could be greater even in the same individual. Banks found that the crypt could develop as early as five and as late as fourteen years of age. The peak time for crypt

formation was observed to be the eighth year. Out of 461 patients aged 15 and over, 19.7% had TMA of at least one third molar. The ethnicity of the sample was not stated.

Figure 2 shows the permanent dentition and Figures 3 and 4 shows the Schour and Massler Atlas [71] and the much more recent London Atlas [72] respectively. These atlases have been considered to be reliable guides for understanding the pattern of dental development and its timing. Their use, including for DAE, continues to the present day. Wide age ranges in third molar development, which are ubiquitous in DAE studies and reference data, greatly compromise the accuracy achievable for DAE in older children and young adults.

Before considering DAE methods, dental variation in morphology, tooth number, and eruption will be considered. These, such as third molar agenesis (TMA) which is considered normal, may affect the timing of dental development.

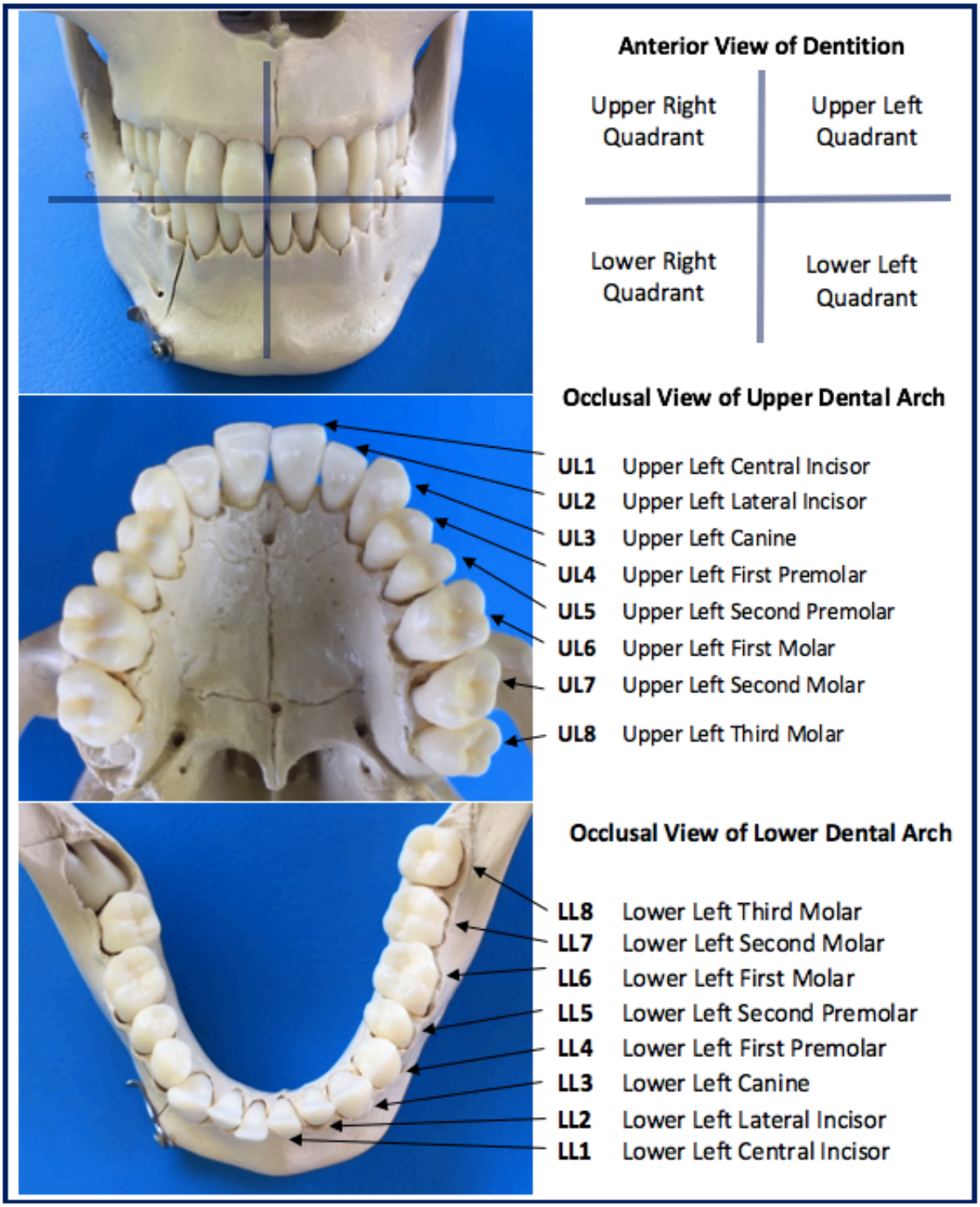


Figure 2. Photographic illustration of the permanent dentition and BDA tooth nomenclature

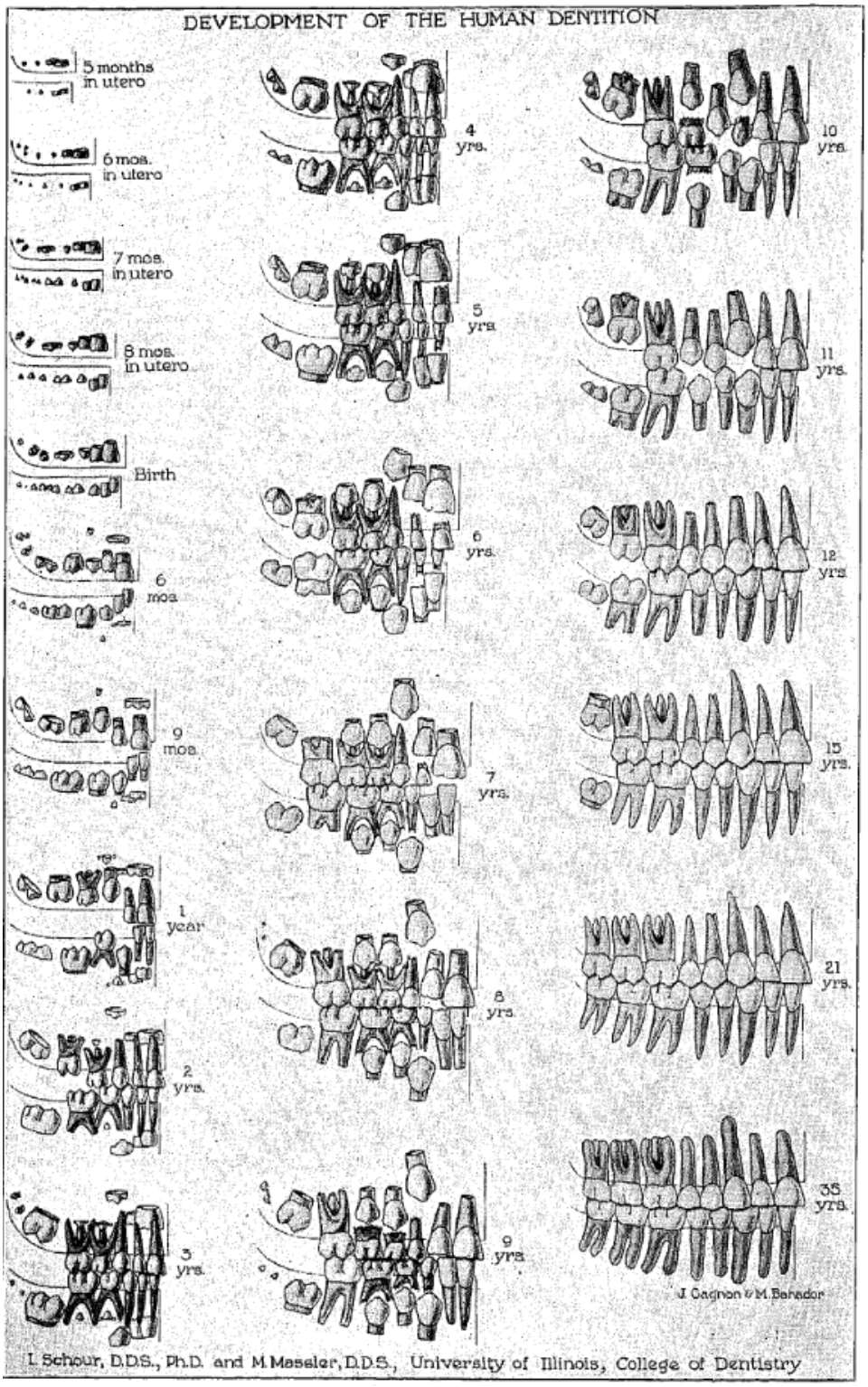


Figure 3. The Schour and Massler Atlas reproduced from the original 1941 article [71] (Permission for reproduction granted by Elsevier.)

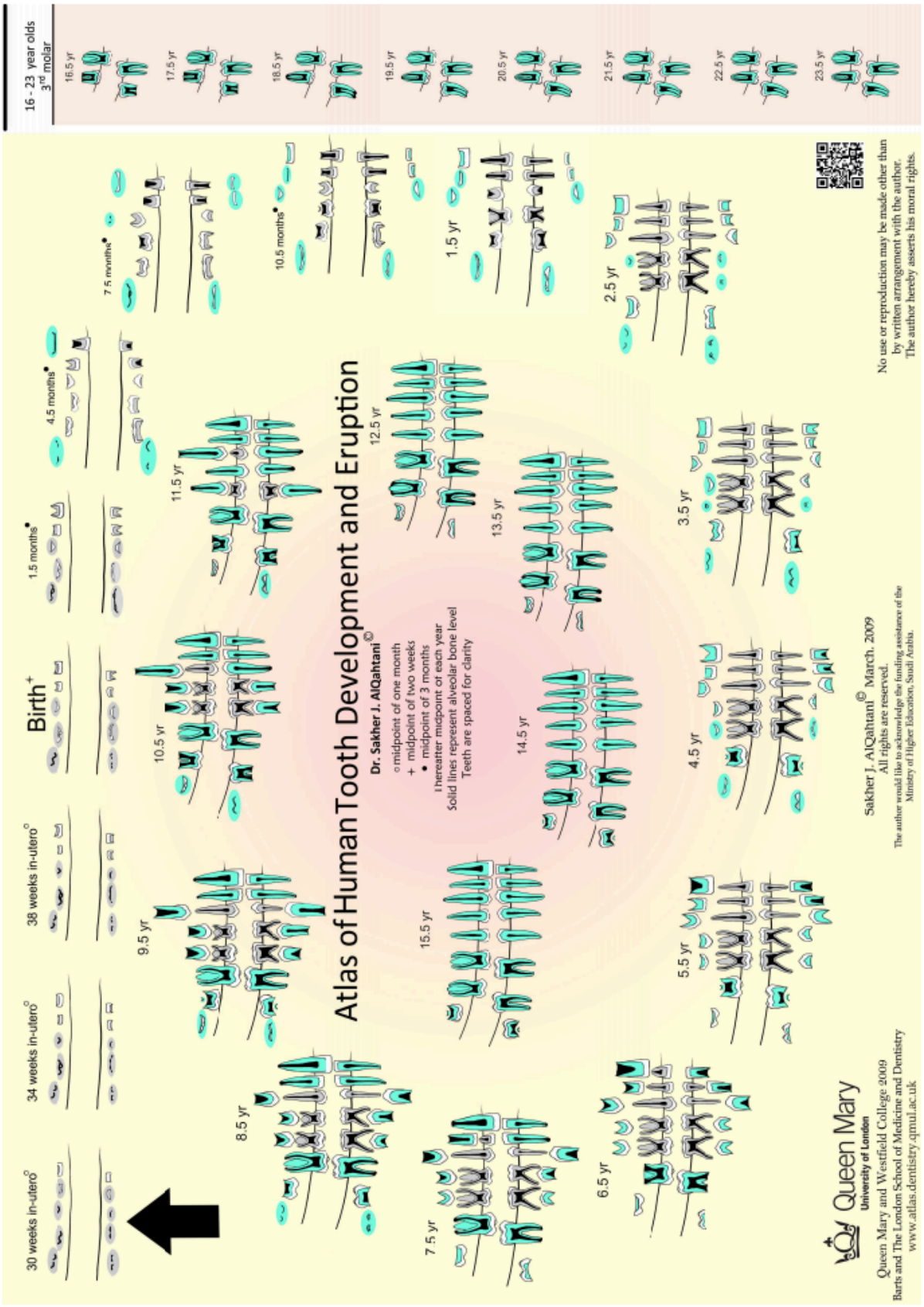


Figure 4. The London Atlas [72] (Permission for reproduction granted by John Wiley & Sons.)

Morphological Variation

All tooth types vary morphologically, but third molars are the most variable in terms of size, shape and root number. Diminutive third molars are characteristically small and conical, and other typical anomalies are small or "peg-shaped" upper lateral incisors. Microdontia describes a single tooth, or whole dentition, much smaller than normal. Conversely, teeth may exhibit macrodontia. Rarely, fused or geminated teeth are seen, giving the appearance of two teeth joined together. Morphological features such as an extra cusp on the palatal aspect of upper molars known as the Cusp of Carabelli are common. More rarely, extra or talon cusps occur, usually on incisors, which differ in size considerably and can mimic a supernumerary or fused tooth. Root anomalies include canines and lower premolars with double roots, and abnormal root shape as seen in taurodontism. Taurodont molars have the root bifurcation set closer to the root apices than normal resulting in a vertically elongated pulp chamber. As with many dental anomalies that are associated with other conditions, this anomaly is seen more frequently with cleft lip or palate and other developmentally missing teeth [73]. Roots may be dilacerated, i.e. the root has a sharp bend or curve, which in upper anterior teeth is often associated with a history of trauma to the deciduous predecessor. Mandibular third molars are said to be most frequently affected [74]. Dilacerations are also reported in several rare syndromes [74]. Root dwarfism, or short root anomaly, with short roots and rounded apices, mainly affects the upper incisors with other anomalies often occurring concurrently and the prevalence is said to be 1.3-2.7% in Caucasians [75]. Radiculomegaly, or root gigantism, is a rare anomaly of abnormally long and large roots. Fused roots and one canal are indicative of pyramidal molars, a feature often seen together with other anomalies such as taurodontism, and mostly affecting upper second molars. Lobodontia is a very rare condition in which canines and premolars have accentuated cusps and molars have cusps resembling rounded tubercles. In globodontia, the premolar and molar cusps are even more rounded, and the condition is associated with other signs such as taurodontism, short roots and pulp stones [76].

Pathological conditions affecting the formation of enamel and dentine, and consequent integrity of the tooth have many forms. Causes of these anomalies can be genetic, systemic, local or unknown and the clinical features depend on the stage at which the enamel or dentine

is affected. Amelogenesis imperfecta is a hereditary condition which affects enamel formation in about 1 in 14,000 people [77]. There are four basic types, which are characterised by hypoplasia, hypomaturation, hypocalcification, and hypomaturative-hypoplasia with taurodontism. All are associated with the need for restorative procedures. Molar Incisor Hypomineralisation affects the enamel of first molars and often the incisors. The cause, although connected with enamel formation in the first three years of life, is unknown [78] although lack of Vitamin D may have a causative role [79]. Radiographically, hypoplastic enamel is thinner but of normal density, occlusal surfaces are flatter especially after attrition with the crowns becoming squarer in appearance, and anterior teeth may have a "picket fence" appearance [80]. In hypomaturation, enamel density is similar to that of dentine and there may be attrition and enamel fractures. In hypocalcification there is normal enamel thickness but its density is less than dentine with attrition and likely enamel fractures. Dentine and roots appear normal although pulps may recede in tandem with attrition.

Dentine defects may feature in syndromes such as osteogenesis imperfecta, Ehlers-Danlos syndrome, Goldblatt syndrome, and some forms of rickets [81], and the appearance may include attrition, tooth discolouration, translucency, short and narrow roots and obliterated or abnormally-formed pulps. In dentinogenesis imperfecta, radiographic characteristics are bulbous crowns with the cervical area being narrowed [80]. Dentine dysplasia has two types: radicular and coronal. Radiographically, both are characterised by pulp obliteration, with short or abnormal roots in the radicular type and pulp stones and "thistle tube" morphology affecting single-rooted teeth in the coronal type [80].

Variation in Tooth Eruption

Developing teeth may fail to erupt or may become impacted against other teeth, supernumerary teeth, or pathological features such as odontomes and cysts. Dilacerated roots or insufficient space, particularly for third molars, may impede eruption. Root formation may be delayed in these cases. Canines in particular may become ectopic and take up unusual positions when their normal path of eruption is lost. Late eruption of the teeth is associated with some conditions including Down syndrome and endocrine disorders such as hypothyroidism, hypopituitarism, and lack of growth hormone [82]. Delayed eruption of

permanent teeth, retention of teeth within underdeveloped jaws, and complete absence of third molars is seen in pituitary dwarfism [83]. Dental dysmorphology has been described as a still largely unknown field [88] and recognition of unusual dental features could allow better understanding of the aetiology of these syndromes and variations in dental development.

Variation in Tooth Number

Agenesis, or failure to form, can affect any tooth but the frequency of this occurrence varies according to tooth type. Third molar agenesis (TMA), or failure of formation of one or more third molars, is so prevalent that it is considered a normal finding. Together with shape, size, and developmental timing, it is a feature which contributes to third molars being the most variable of human teeth. Agenesis of premolars, especially lower second premolars, and upper lateral incisors is often found. While complete absence of teeth, anodontia, is very rare, hypodontia, meaning up to five missing teeth not including the third molar, occurs more often. Oligodontia is a term describing severe hypodontia with at least six developmentally missing teeth excluding the third molars. Upper central incisors, lower first molars and canines are the least likely teeth to be missing [84]. There are known ethnic variations, with hypodontia in Chinese populations most often affecting lower central incisors, 80% of Caucasians showing hypodontia of some degree, and Black Americans having a significantly lower incidence of hypodontia [85].

Hypodontia is a feature of more than 50 syndromes including Down syndrome and dentoalveloar clefts [86]. Other conditions which are associated with congenital absence of teeth include Wolf-Hirschorn syndrome, Kallman syndrome, ectodermal dysplasia, incontinentia pigmenti/HED/immune deficiency[87], lacrima-auriculo-dento-digital syndrome[88] and mutation-related syndromes.

More than 200 genes are thought to be involved in tooth agenesis [95]. The AXIN2 gene is known to be inherited as an autosomal dominant disorder affecting hypodontia of second and third molars, second premolars, upper lateral incisors, and lower incisors. PAX9 mutations are associated with missing molars and the MSX1 gene with missing third molars and second premolars most commonly, but also upper first premolars and upper lateral incisors [95].

In 1934, Schultz constructed a family tree showing family members with missing third molars and upper lateral incisors which may possibly be the earliest example of a genetic study of tooth agenesis [112]. In 1968, Berry found that the frequency of TMA is about 5 or 6 times higher in first degree relatives, i.e. offspring, parents or siblings with TMA than in the general population [89]. A study of a large family led to the identification of a mutation in the MSX1 gene which affects the formation of third molars and second premolars [90]. In 2013, Haga et al reported that although variants in several genes, such as MSX1, PAX9 and AXIN2 have been associated with tooth agenesis not including the third molar, susceptibility genes or loci for TMA were unknown. Haga et al carried out a genome-wide association study of a Japanese and Korean sample of subjects with TMA, analysing approximately 550,000 single-nucleotide polymorphisms (SNPs) to investigate this [91] . Subjects with TMA (n=149) were compared with subjects not exhibiting TMA (n=338). This is reported to be the first such study to identify genes associated with TMA diagnosed by their absence on a DPT. Three SNPs, located in three independent loci, were identified. The strongest association was found with SNP rs1469622. While this gene has been shown to be associated with bipolar disorder, pancreatic cancer and alcohol dependence, its biological function is otherwise unknown. Two other SNP's linked with TMA were found which have no known biological functions. No SNPs were found with significant associations with genes previously reported in connection with non-syndromic tooth agenesis which suggested an independence of TMA compared to the agenesis of other teeth.

It has been suggested that TMA is possibly induced by local anaesthesia, lower third molars being affected by inferior alveolar nerve block [92]. From around the age of six, when the third molar is beginning to form, this technique is often employed if lower first molars require treatment. Local anaesthetic solutions have been found to accumulate in crypts of developing teeth of dogs [93] and, in another study of killed pigs' mandibles, cause autophagy of dental pulp and, by inference, developing tooth germ cells [94].

Supernumerary or supplemental teeth occur occasionally and are most commonly seen as fourth molars, extra premolars, or a mesiodens developing in the midline of the upper arch. A mesiodens is usually conical and unlike the incisors forming in the same region. Supernumerary teeth are often smaller than the teeth they resemble. Fourth molars are often diminutive. Black Americans show increased frequency of supernumerary teeth up to nine times higher than White Americans and twice as likely in males compared to females [95]. Supernumerary teeth are seen in cleido-cranial dysplasia, Gardner syndrome, and Nance-

Horan syndrome [88]. These syndromes may be characterised by diminutive or unusual tooth morphology. Odontomes formed of enamel and dentine but of no recognisable tooth shape also occur.

Prevalence and Population Variation in Third Molar Agenesis

In 1930, Goblirsch [96] made a radiographical study and reported an incidence of TMA affecting at least one third molar in 9% of 2112 White American subjects. In 1934, Banks examined radiographs of patients of unstated ethnicity between 6 and 22 years from a Colorado orthodontic practice [70]. Out of 461 patients aged 15 and over, 19.7% had TMA of at least one third molar, and these were most commonly missing two third molars, followed by one, four and three. In an analysis of 92 studies, it was found that the likelihood of having one or two third molars missing was significantly higher than having three or four missing; and the high occurrence of bilateral TMA was noted [110].

In 1936, Hellman reported a study of 735 male and 314 female skulls representing 19 ethnic groups and finding that TMA was seen in all groups except Tasmanians. TMA ranged from 2.6% in West Africans to 49% in Caucasians from Hungary and occurred more frequently in females than in males [97].

In 1954, Nanda [100] examined the dentition of 200 Caucasian females from Boston between 18-21 years of age, with known dental histories, clinically, radiographically and using dental casts. TMA of one or more third molars was found in 9%. Of these individuals with TMA, 61.1% had one third molar absent and 5.5% had all four third molars missing. Suggesting that TMA should be studied in conjunction with tooth size, Nanda found that 3% had, in addition to TMA, extreme diminution in the size of some of the third molars that were present. Diminutive third molars, were only seen in the maxilla and in individuals with TMA and this finding led to the suggestion that TMA and diminution may have a causal relationship [100]. Diminutive upper third molars associated with the missing antimere has been documented since 1905 [98]. A study of Japanese males and females indicated that about 2% exhibit diminution of the third molars with 93.4% of these teeth being found in the maxilla [99].

In the 1930's, it was suggested that diminutive third molars were vestigial or an evolutionary reversion to conical tooth form while TMA was an evolutionary trend towards eventual disappearance [100]. Apart from the possible argument that missing third molars remove any problematic sequelae of possible impaction or pathology associated with these teeth, there is no evidence to support the idea that TMA is an advantageous evolutionary trend. Conversely, the successful addition of functioning third molars in the dentition would seem the ideal. Whilst it is true that discrepancies between tooth size and jaw size may result in impaction of third molars and possible consequential problems, not least including those involved with their removal, TMA occurs in both crowded and uncrowded dentitions which further fails to support theories of an evolutionary advantage associated with the lack of third molars. In a review of TMA studies, a wide range of TMA frequency between population groups of almost none to almost 100% was seen but the authors noted that TMA appears to be a developmental anomaly associated with mutation and heredity and stated the current opinion that the human dentition has stabilised at eight teeth per quadrant [101]. Garn and Lewis suggested that the marked prevalence of TMA in an isolated Tristan da Cunha population could be explained by "chance assemblage of rare genes" [102].

In 1960, Chagula examined 188 skulls of adult African males [251], taking radiographs when no third molar was visible and found that 1.6% of mandibular third molars were developmentally absent.

On examination of dental casts and radiographs of 149 females and 152 males, all White British from the Birmingham area, aged 18-25 years, TMA was found in 13.7% of males and 16.9% of females, the sex difference being insignificant [103]. A few years later in 1973 in, to my knowledge, the only published evidence of TMA in UK subjects of Black ethnicity, the same author, Lavelle, published another study investigating the incidence of agenesis of all tooth types in 1,562 primate skulls and a sample of 5,000 living humans aged 18 to 40 years, 1,000 of Black ethnicity and 4,000 of White ethnicity [104]. Radiographs and a history were taken to augment the diagnosis. In marked contrast to other studies mentioned in this review, this study found 24% TMA in the Black ethnic group and 25% in the White ethnic group.

Harris and Clark studied hypodontia in 600 Black Americans and 1,100 White Americans using DPT's of unrelated 12-18 year-olds with no syndromes contributing to tooth agenesis. There was a statistically significant difference between the two ethnic groups for hypodontia,

particularly for TMA, the odds ratio for White Americans being 3.18 higher for all quadrants combined. Hypodontia overall was 11% in Black Americans and 27% in White Americans [105]. The ethnic difference was particularly large for teeth most prone to agenesis, that is, third molars and second premolars. TMA was found to be significantly more common prevalent in females. Sex differences were found only in TMA and were greater in the White American group. It was concluded that studies based on Caucasians do not readily apply to other ethnic groups.

Other studies report the frequency of TMA as 15.2% in a New Zealand population [106], 20.9% in a Northern Greece population [107], 27.2% in a Jordanian population, 28.5% in a Chinese population, 23% in a Japanese population, 24% in an Asian Indian population, and 23.8 % [108] and 17.3% [109] in two separate Turkish studies.

In a recent review and meta-analysis of TMA, the average worldwide rate of TMA is given as 22.63% while the range found in the review is between 5.32% and 56.0% across 92 studies based on radiographic examination with subjects aged at least 11 years. Asian populations showed the highest frequency of TMA while African populations showed the lowest. It was found that population TMA frequencies were seen to be similar in both archaeological and modern studies [110]. The authors noted that a limitation of their study was lack of data from Africa and remarked on the need for further work in understudied population groups. Females were found to be 14% more likely to have TMA than males, and the preponderance of females with agenesis of other teeth is even higher [110].

In a sample of 4,640 15-19 year-old French-Canadians studied by Levesque, Demirjian and Tanguay, agenesis of both lower third molars was found in 9.0% [162]. In a sample of 205 14-24 year-old White and Bangladeshi UK citizens, all with TMA, one missing third molar was found in 45% of the sample, while 34% had 2 missing, 6% had 3 missing and 15% had agenesis of all four third molars; and sex and ethnic differences were not found to be significant [111]. Most studies find that there is more TMA in the maxilla than the mandible but in the Northern Greece population [107], a study of 428 orthodontic patients with a mean age of 13.62 years, showed the third molar most likely to be absent was the lower right third molar (10.9%), followed by the lower left, upper right and upper left (8.1%) third molar respectively. In this study, eighteen individuals had agenesis of one or more third molars;

8.6% had one missing third molar; 7.7% had two missing third molars; 1.8% (4 patients) had three missing third molars and 2.7% had agenesis of all four third molars.

Third molar agenesis and hypodontia

The first report of TMA being associated with absence of other teeth is claimed by Schultz [112] who studied the absence of third molars and incisors in skulls of monkeys and apes and commented on similar findings in the human dentition.

In 1962, Garn and Lewis drew attention to the association of TMA with agenesis of other teeth and recommended that TMA should not be studied in isolation but rather that other missing teeth should be incorporated [113]. Having noted TMA ranging between 7% and 26% in earlier radiographic studies of White American groups, and up to 50% in some ethnic groups, other teeth being more frequently missing in association with TMA were investigated. As well as third molars, second premolars and lateral incisors are the most distal teeth in their segment as proposed in the field theory of tooth development. Garn and Lewis reasoned that this theory may have bearing on missing second premolars and lateral incisors when third molars are missing [113]. Having confirmed 14 years as the latest age for third molar crypt formation, patients of over 14 were chosen and radiographs of a control group of 398 orthodontic patients with all four third molars and 100 orthodontic patients with one or more missing third molars were examined. It was found that far more teeth of other types were missing in the TMA group compared to the control group. In the TMA group, the most commonly missing teeth were the lateral incisors and second premolars with only the first molars being consistently present in all cases. In the control group, the only teeth found missing were the lateral incisors and second premolars and this incidence was much lower than in the TMA group [113]. In this study, 75% of all missing teeth were associated with TMA showing the strong relationship between TMA and agenesis affecting other teeth. It was stated that if one or more third molars are missing, the incidence of other missing teeth rises thirteen-fold [113].

Patterns of missing teeth associated with TMA have been investigated more recently. In a sample of 374 Turkish girls and boys aged 13 -17 years, DPT's and dental models were used

to detect TMA and dental anomalies [114]. TMA was significantly associated with agenesis of other teeth and this was more commonly seen when there were 3 or 4 missing third molars. Patients with 4 missing third molars showed diminutive upper lateral incisors more frequently than those without TMA. In patients with one or more missing third molars, 11.2% showed agenesis of other permanent teeth (n=42) while the prevalence for those without TMA was 4.1% (n=4).

Tooth Agenesis and Delayed Dental Development

Both TMA[115] and hypodontia [116, 117] have been associated with delayed dental development. Garn and Lewis note that in their earlier studies TMA is associated with substantially delayed development and eruption of premolars and molars. They also observed that when the third molar is missing, the second premolar develops ahead of the second molar but this sequence is reversed when the third molar is present [113].

In 2016, while excluding the third molar, a Belgian study evaluated hypodontia in permanent teeth on the left side from radiographs of 1,145 subjects with hypodontia aged 6.2-24.8 years with a mean of 12.0 years, and 2,032 subjects without hypodontia, to investigate a possible association with delayed development [117]. An association was shown, together with a weak positive relationship between the number of missing teeth and delayed dental development. The authors concluded that agenesis would need to be taken into account in DAE.

Delayed dental development in association with TMA was also found in a study of 700 Australian 10-16 year-olds [115]. Demirjian's method was used to evaluate dental development and a highly significant difference was found between chronological age between the subjects with and without TMA. Dental development was delayed in subjects with TMA but not affected by the number or site of the missing third molars.

Down syndrome is characterized by late eruption and greatly increased TMA [118].

Teeth as a Test of Age: DAE Methods

The observance of teeth in the mouth has long been advocated as a method of age estimation. The Ancient Romans used the appearance of the second molars as an indication that a boy was old enough for military service [119]. In England, the 1833 Factory Act provided that children under nine years of age should not be put to work in the textile mills that became synonymous with the Industrial Revolution and that children under 13 should not work more than 48 hours in a week. A method to protect young children from exploitation was presented to Parliament in 1837 by Saunders, who had noticed that the development of the dentition appeared to progress more according to age than did physical appearance [120]. He was also aware of Thomson's statement published in the Lancet within the same year in connection with the seven year-old threshold of criminal responsibility that "if the third molar tooth (i.e. the first permanent molar) have not protruded you can have no hesitation in affirming that the culprit has not passed his seventh year" [121]. Saunders' description of teeth as a test of age was based on clinical observation of erupted teeth in 1,046 nine and 13-year-old children from London schools. Saunders was able to say that the presence of all permanent incisors would be indicative of a child having reached the age of nine and, if canines and second molars were present, 13. The range was stated and the accuracy of the method tested in 1838 with a sample of 307 children of known age at the London Orphan Asylum [120, 122]. Saunders commended the method to "those who are anxious that nothing should be left uninvestigated or unproved that shall tend in the slightest degree to ameliorate the condition of that large, unprotected and suffering class of the community, the Factory Children."

Nearly two centuries later, the need for an accurate age assessment method is ever present. Many methods have been suggested and dental age estimation (DAE) has become an established practice. However, although DAE is helpful in many scenarios, the reliability of any method for the correct determination of a legal age threshold is questionable.

Methods involving clinical observance of teeth compared with descriptions or pictorial representations of developing teeth were relied upon for age estimation until dental radiography became widely available. The main difficulty with clinical observation is that no information is available about root development or tooth agenesis, i.e. failure of formation. Factors such as third molar eruption being likely to occur earlier when a molar anterior to

them has been removed [123], or impaction influencing or preventing eruption, need to be considered. Clinical or so-called tooth count methods are now regarded as inadequate for DAE and have been superseded by methods using radiographs.

A list of the most well-known DAE techniques is as follows:

- Tooth Counts based on clinical observation

  Descriptive [120]

  Atlas [29, 124, 125,126, 71, 72]

- Radiographic appearance of developing teeth – Atlas methods

  Logan and Kronfeld [29]

  Schour and Massler [125]

  The London Atlas [72]

- Radiographic appearance of developing teeth – Staging methods

  Gleiser and Hunt Method [127, 69]

  Kohler's method [128]

  Nolla's method [129]

  Moorree's method [161]

  Haavikko's method [130, 131]

  Nortje's method [132, 133]

  Demirjian's method (with four [134], seven [134] and eight [65] teeth)

  DARLInG (Dental Age Research London Information Group) method [157, 156]

  Willems' method [169, 135]

  Olze's method [287]

- Radiographic appearance of developing teeth – Measurement methods

  Kvaal's method [136]

  Cameriere's method – ratio of root width to length [39, 137, 138]

- MRI – with Demirjian or other staging method [139, 140]

- Later radiographic changes in third molars:

  Root pulp visibility (RPV) [172, 174, 141]

  Root canal width (RCW) [177]

- Later changes in tooth morphology in the adult dentition

  Tooth wear, attrition [142]

  Secondary dentine apposition - root translucency [142, 143, 144, 145]

  Secondary dentine apposition – decrease in size of pulp chamber and root canals [142]

  Cementum apposition [142, 146]

  Root resorption [142]

  Periodontal ligament attachment position [142]

- Changes in surrounding structures

  Changes in periodontal ligament visibility [175]

  Loss of bony support [142]

- Microscopy of extracted teeth

  Incremental lines in enamel and dentine [147]

Neonatal line [148]

- Tooth biochemistry

  Aspartic acid racemization [153,149, 150,151]

  Radiocarbon dating [152]

Techniques to assess later changes throughout adult life, and those requiring microscopy or biochemistry, are generally not used for age estimation in the living. If an extracted tooth becomes available for forensic identification purposes in the deceased, or for therapeutic reasons in the living, microscopic and macroscopic age changes can offer information for estimation of age. Techniques based on amino acid racemization and carbon dating can also be employed using an extracted tooth or even by etching away part of the enamel of a tooth in situ in a living person [153] .

Radiographic methods determine the degree of tooth development visualised on a radiograph by allocating tooth development stages (TDS) to developing teeth [154], by taking measurements, such as the ratio of root length to width [155], or by assessing later changes to the pulp size or periodontal ligament space [174, 175, 177]. The dental panoramic radiograph, or tomograph (DPT) (Figure 5) is now the standard requirement for DAE in the living.

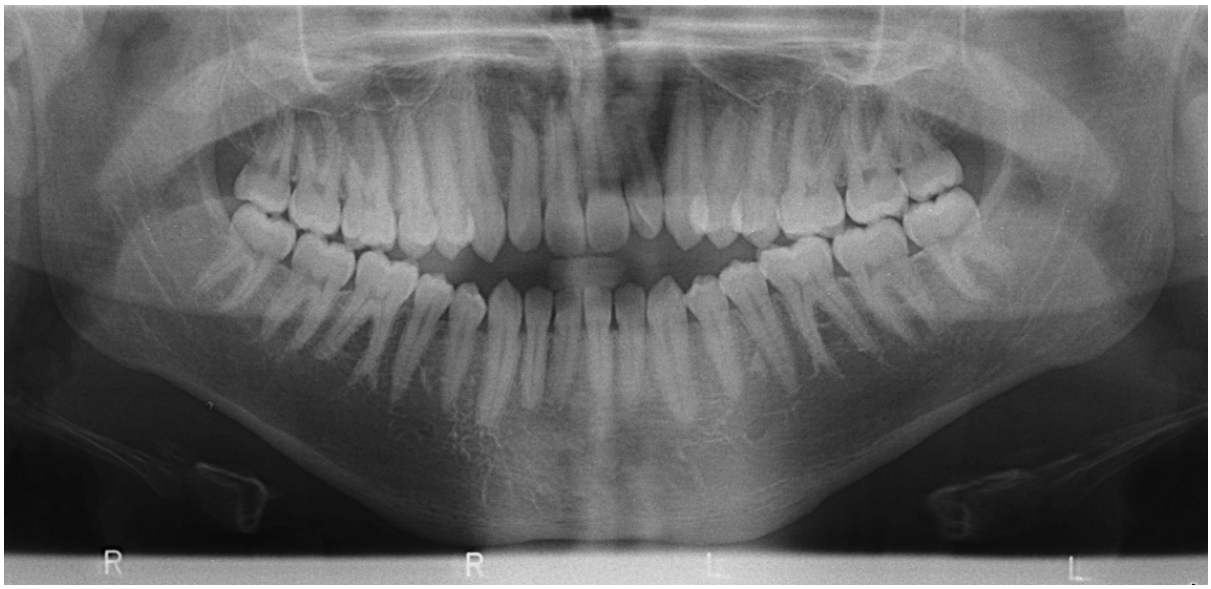


Figure 5. Example of a DPT showing fully developed dentition including third molars in a White British male aged 20 years.

The techniques applicable to children and young adults, particularly at the 18-year-old threshold, will be further described below.

The London Atlas (Figure 4 on page 30) is generally considered reliable for DAE in many situations involving young children. The atlas does not consider males and females separately and assumes no ethnic difference in dental development. The sample for 2-24 year-olds comprised 528 of White and Bangladeshi individuals with 12 males and females in each yearly group. Data for the younger age groups was taken from 176 skeletal examples in museum collections [72]. From age 16, an average stage at yearly intervals is illustrated which makes estimating age very imprecise. In common with all DAE methods, results become less precise as individuals advance in age.

Of the staging methods, the Demirjian and Moorree's staging schemes have attracted the most interest regarding DAE studies in the living and in recent decades. There are thirteen Moorree's TDS which describe the proportion of development in various areas of a developing tooth, e.g., whether roots are a quarter, half, or three-quarters complete. A drawback with this scheme is difficulty making such decisions when the completed size of the tooth is unknown. The Gleiser and Hunt, Kohler, Nolla, Haavikko, and Nortje staging schemes are similarly indeterminate. The eight Demirjian TDS are not dependent on

prediction of the final size of a developing tooth. This number of TDS has been shown to allow good differentiation of TDS balanced with little potential overlap of TDS.

DAE based on a dental panoramic radiograph, or tomograph (DPT) (Figure 5), and using the Demirjian TDS (as shown in Figure 1 on page 25) is described as the most reliable method of age estimation in a young person [156] and considered to be the most accurate and reliable way to determine chronological age at the 18-year-old threshold [157]. It has been claimed that "the only thing that provides more reliable information is an authentic birth certificate" [158]. It has been claimed that the age of British Caucasians at the 16-year-threshold can be predicted to within 0.3 years of an individual's chronological age [159]. More difficulty arises around the 18-year-threshold as the third molar is notoriously variable in its developmental timing as well as morphology. Left and right development may not be consistent, nor the probability of mandibular teeth being ahead of maxillary counterparts, as with most other teeth. Also, although not shown in a study regarding Americans of Black ethnicity [160], third molars generally erupt earlier in males than females [161, 162, 163], reversing the usual pattern for other permanent teeth [164]. Sex-specific reference data is therefore regarded as important. The same regard has not been paid, at least in the past, to ethnicity.

The Demirjian Method

The method first described by Demirjian, Goldstein and Tanner relies on the determination of a TDS for each mandibular left-sided tooth seen in a DPT according to the eight stage scheme, signified by the letters A-H, now well known as the Demirjian Stages, as seen in Figure 1 (page 25) [65]. Using the TDS results, a "maturity score" is found according to the published data and this is then used to look up an estimated chronological age in tables. Originally published using data from 2,928 French-Canadians aged 2-20 years and without consideration of the third molars, subsequent versions have incorporated third molars or used different combinations of teeth.

Several methods which compare chronological age with dental age based on Demirjian Stages have been devised for DAE purposes which omit the step of calculating a maturity score. Quicksheets© as designed by Derek Draft in the USA [165, 166] is such an example which

uses the DARLInG method. This system compiles RDS summary data for each TDS of each left-sided tooth and all third molars within a Microsoft® Excel™ workbook. The front sheet of the workbook is set up so that when the user selects, from drop-down lists, the TDS for teeth seen on a DPT, their summary data is collected automatically from the relevant worksheets. An estimated age is presented to the user on this front sheet using Excel formulae to calculate an average mean age using the collated reference data for all the teeth observed, together with an age range. The calculations can follow those for the Simple Average Method [191, 154, 232, 167], by calculating the mean of the mean ages for each available developing tooth to give an estimated dental age, or use the Weighted Average Method [168] as recommended by DARLInG. These methods also incorporate the maxillary left-sided teeth as well as all four third molars. The DARLInG [157] and Willems [169] methods, while still relying on Demirjian TDS but with their own RDS, claim greater ease of use and accuracy and are gaining popularity with the latter having now been tested on several populations [170, 171].

It is important to note that, as in the present study, the Demirjian Stages can be used alone as a staging system in order to directly compare developmental timing in different datasets without attempting to produce correlations of dental age with chronological age.

Radiographic Stages of Eruption

With particular relevance to the 18-year-old threshold and third molars, Olze et al published a 4 stage system, A-D (Figure 6), where the radiographic appearance of teeth is evaluated according to their position within their bony crypts or emergence through bone or gingiva. This system has been used to evaluate the timing of dental development in various populations [244, 247, 248, 249]. Estimating gingival emergence, Stage C, from the radiographic image can be difficult where the gingival level is not clearly recognisable. Some estimations cannot be made, while others are said to possibly lead to more scores of C than really justified. Equally, the 2D radiographic appearance might not reflect that, in reality, one cusp is actually through the mucosa.

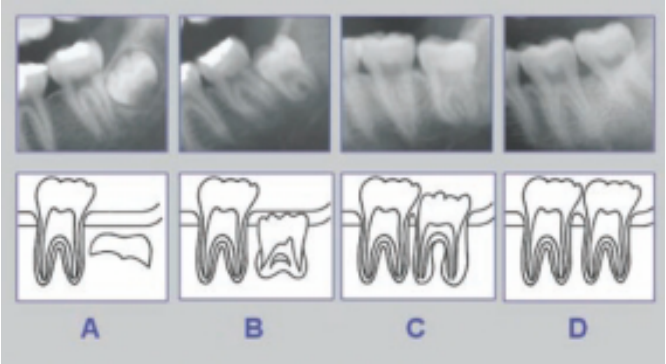


Figure 6. Olze Stages of wisdom tooth eruption [287]. (Permission for reproduction granted by Spinger Nature.)

Stage A Occlusal plane covered with bone

Stage B Alveolar emergence; complete resorption of alveolar bone over occlusal plane

Stage C Gingival emergence; penetration of gingiva by at least one dental cusp (partially erupted)

Stage D Complete emergence in occlusal plane (fully erupted)

Measurement Methods

Measurement methods used in conjunction with radiographs include Cameriere's method of assessing the ratio of the length of the tooth to the width of the developing open apex or apices. This method was originally applied to the developing teeth on one side of the mandible [138] but has since been modified for use with the third molar when it is the only developing tooth around the 18-year threshold [155]. A ratio, termed the third molar maturity index, $I_{3M,}$ was defined as the sum of the distances between the inner sides of the two open apices divided by the tooth length as shown in Figure 7. If the third molar apices are complete the $I_{3M} = 0$. A cut-off of 0.08 for the I_{3M} index representing the 18-year-old threshold was derived from the evaluation of DPT's of 906 Caucasian subjects aged between 14 and 23 years. The authors claim that the choice of the third molar maturity index, $I_{3M} < 0.08$, is the most suitable method of determining the 18 year-old threshold for forensic purposes. The drawback with this method is that very small measurements of

fractions of millimetres are difficult to make in practice because, especially at high magnifications, the inside edges of the apices are not well-defined. Also, if a tooth is lying at an angle, in a bucco-lingual plane, the ratio is affected by foreshortening or lengthening in the 2D radiographic image.

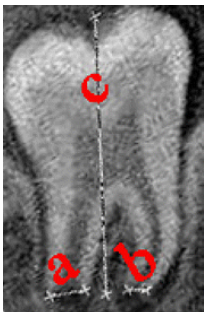


Figure 7. Cameriere's Method: an example of measurement of a tooth with two roots (as illustrated by Cameriere) [155]. (Permission for reproduction granted by Springer Nature.)

Mandibular Maturity Markers

Also visible on DPT's are changes in Root Pulp Visibility (RPV), Periodontal Ligament Visibility (PLV), and Root Canal Width (RCW) as described by Olze et al [172, 173], Lucas et al [174, 175, 176], and Roberts et al [177] which focus on details associated with the changes in molars after root completion with the intention of increasing accuracy of DAE in young adulthood and have been termed collectively as Mandibular Maturity Markers (MMM) [174, 175, 177].
In 2010, Olze et al suggested that the radiographic visibility of the root pulp in third molars could potentially be used for age estimation [172]. A staging system was introduced, illustrated in Figure 8, with stages defined as 0 = the lumen of all root canals is visible all the way to apex; 1 = the lumen of one root canal is not fully visible to the apex; 2 = the lumen of two root canals are not fully visible to the apex, or one canal may be virtually invisible in full length; 3 = the lumen of two root canals is virtually invisible in full length. In the study, DPT's of 1198 German subjects between the ages of 15 and 40 years were examined. Results showed that age increased with each stage. The effect of the disappearing pulp was acknowledged to be an optical phenomenon and stated to be because of secondary dentine deposition. The method was suggested as useful for excluding individuals from being under 18 years old if the stage of RPV is 1, 2 or 3.

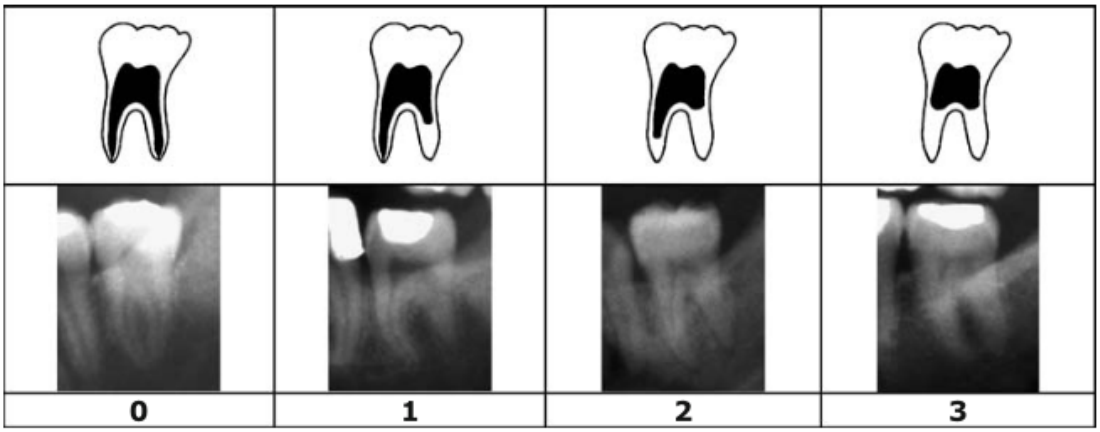


Figure 8 Schematic drawings and pictures of the stages of radiographic visibility of the root pulp in third molars (Olze et al) [172]. (Permission for reproduction granted by Springer Nature.)

In a further study [178] of 2,346 German subjects, 15-70 years of age, it was confirmed that males and females with stage 1 were over 18 and that at stage 2 they were all over 21. It was also noted that age estimation could not be made in older age groups because stages 1, 2 and 3 were seen in individuals of 70 years of age.

Lucas et al studied RPV in 2,000 Caucasian subjects aged 16.00-24.99 years of age and claimed that stages, renamed A-D to reflect the observation that pattern changes are not on a numerical scale, equivalent to Stages 2 and 3 in Figure 8, in males and females indicates unequivocally that the subject is over 18 years of age.

A method of assessing the visibility of the periodontal ligament of the lower third molars for age estimation was also first published by Olze et al in 2010 [173] with four stages from Stage 0 where the periodontal ligament is visible along the length of the roots to Stage 3 where it is invisible along almost the full length of the roots. The stages were renamed A-D by Lucas et al [175] (Figure 9). This gradual disappearance of the periodontal ligament space on a DPT is an unexplained optical phenomenon, possibly due to increasing thickness of adjacent bone, as the periodontal ligament remains clinically present. PLV Stages A-D (Figure 9) are as follows:

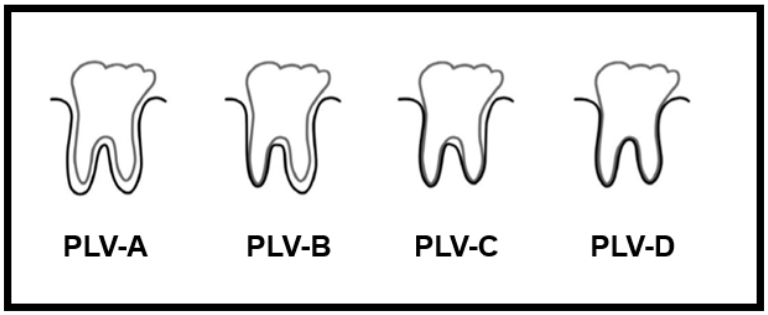


Figure 9. Stages of periodontal ligament visibility (PLV) (after Olze et al 2010) [175] (Permission for reproduction granted by Springer Nature.)

Lucas et al concluded that once Demirjian Stage H has been reached, the PLV stages can give very high confidence in assigning a subject as over 18 years old [179].

In 2017, Roberts et al published a method of age estimation using stages by visually assessing the relative root canal widths (RCW) of the three lower molars [177]. RCW-A is allocated when the RCW of the first molar (LL6) is narrower than that of the second molar (LL7) which, in turn, is narrower than that of the third molar (LL8). In RCW-B the LL6 and LL7 RCW's are the same but narrower than that of the LL8. In RCW-C, the three RCW's are equal (Figure 10).

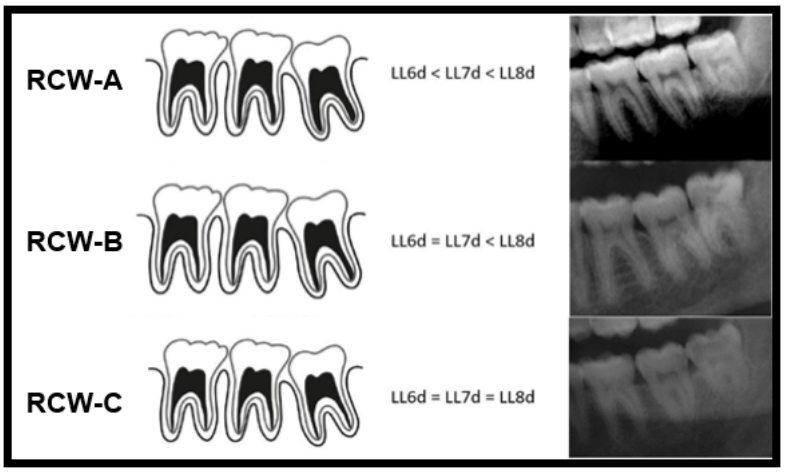


Figure 10. Stages of Root Canal Width (RCW) (Roberts et al 2017) [177] (Permission for reproduction granted by John Wiley & Sons.)

In 2,000 Caucasian subjects aged 16.00-24.99 years of age, the minimum age in years seen for RCW-A was 16.33 in females and 17.16 in males; for RCW-B it was 17.23 in females and 18.29 in males; and for RCW-C it was 18.45 in females and 18.16 in males. It was

therefore concluded that the presence of RCW-C in a female or RCW-B or RCW-C in males is compelling evidence of having reached the 18-year-old threshold [177].
Although thought to have potential for differentiating the age of young adults at the 18 and 21-year-old thresholds, MMMs represent relatively novel indicators of age, few studies have been carried out, and the methods have yet to gain acceptance. The changes described by the MMM stages, while likely to reflect growth patterns of the mandible, remain so far unexplained.

1.5 Age Assessment Procedures at the 18-Year-Old Threshold

Until May 2019, if no credible documentation was available, an asylum seeker was deemed an adult when in the opinion of the UK Border Force "their physical appearance and/or general demeanour very strongly indicate that they are significantly over 18 years and no other credible evidence exists to the contrary" [180]. Physical appearance was tested by visual appraisal of stature and the face and hands [181].

Fundamentally, it is a breach of the human rights of any child to be treated under the law incorrectly as an adult [7] but there are many instances of hardship and wrongful detention in immigration centres [182]. If a child was assumed to be an adult, it could be very difficult for the child to appeal the decision. In 2017, a High Court Judgement ruled that it is unlawful for the Home Office to detain a person assessed at the time of detention to be an adult over the age of 18 if it later transpires that the detainee was a child under the age of 18 [183].

According to new guidelines published in May 2019 [184] , the UK Home Office applies three tests of adulthood. These are documentary evidence, physical appearance/demeanour, and Local Authority age assessment. While a claimant is considered to be an adult if there is credible and clear documentary evidence that they are 18 years of age, the new guidelines have made a considerable change to the test of physical appearance. It is now stated that "a decision should only be made to treat the claimant as an adult if two Home Office members of staff, one at least of Chief Immigration Officer or Higher Executive Officer grade, have independently assessed that the claimant is an adult because their physical appearance and demeanour very strongly suggests that they are 25 years of age or over". This offers more protection for traumatised, unaccompanied children who, in the past, were disbelieved when

being truthful about their age and were unlawfully detained or denied social services support which would otherwise have been provided in the absence of a family unit.
The new approach has increased adherence to the fundamental "benefit of the doubt" principle in age assessment set out by the United Nations High Commissioner for Refugees' (UNHCR) guidelines relating to child protection under the 1951 Refugee Convention and its 1967 Protocol [185].

The third option in the new Home Office guidelines for treating the claimant as an adult is if "a local authority Merton compliant age assessment has been completed by a local authority finding the claimant to be 18 or over, which the Home Office has agreed with after giving significant weight to the assessment taking all reliable evidence into account" [17].

Although the result might be that more adults are designated as children, age-disputed cases where an asylum seeker disagrees with the decision and is able to find representation in the Court system, may become less frequent with the new guidelines. Age-disputed cases amounted to about 800 per year between 2016 and 2018 [186] mostly originating from Afghanistan, Sudan, Eritrea, and Iran. In the year ending June 2019, there was an annual increase of 32% in grants of asylum to UASC and 959 age disputes were raised [187]. In the same year, 787 age disputes were resolved, 465 with the asylum seeker being over 18, and 322 being decided as UASC aged under 18.

When there is uncertainty or once a young person's age becomes disputed, Local Authorities are required to undertake an independent age assessment subject to the Merton Test [188]. This takes into account the physical appearance of the individual, psychological maturity and behaviour. Two qualified social workers carry out the assessment interview with an interpreter and an advocate for the young person from an organisation independent of the local authority. Guidelines and a proforma assist social workers through the age assessment which is meant to include the applicant's general background with an understanding of ethnic and cultural considerations, family circumstances and education [189]. The aim is to consider as much as possible of the young person's development and chronological age, without any clinical intervention or medical examination and this has become known as the holistic method. Information can be drawn from people who know the applicant such as teachers, advisors, and key workers. In the event of remaining uncertainty, the individual should be given the benefit of the doubt and considered a child. Decision-making is clearly made

difficult by potential misunderstandings of unfamiliar backgrounds, social values, education and knowledge and the effect of traumatic experiences on the behaviour and development of vulnerable people. Furthermore, there is a lack of scientific research on the reliability of psycho-social age estimation.

The judicial system is ultimately responsible for determining a young person's age if the local authority assessment is challenged [190]. In 2016, Upper Tribunal Judge (UTJ) Ockelton, said that there is no reason at all to suppose that a judge, looking in detail at the evidence made available in a single case, is any better at determining a person's age than competent social workers constantly dealing with young people, some of known and some of unknown age, and said that the reverse is probably true. He stated that "everybody knows that there is no sure way of assigning a chronological age to an individual, particularly a teenager or late teenager, on the basis of physical, mental or social characteristics"; and said that "the only certainty about this system, although satisfying the demands of the law, is that heavy demands are made on the public purse however irrational it may be to regard the results as either correct or an improvement on any other age assessment method" [191].

An example of the life-changing consequences for vulnerable asylum seekers following an incorrect age assessment concerns 'Miss T', a girl from Cameroon, who was sexually abused whilst being denied support and protection for more than fifteen months. The Local Authority had wrongly concluded that she was 23 when she was in fact 15 years old [192].

The European Union (EU) guidelines [193] make it clear that in cases where the person whose age is in question has suffered such trauma or abuse that age assessment may cause possible further harm, the benefit of the doubt should be largely applied. The most recent guidelines from the Home Office, UK judiciary, UNHCR, and refugee support workers universally agree on this principle.

Once the Courts are required to decide the age of an individual it has been accepted that scientific methods of age assessment are indicated [194]. These methods rely on measurable clinical features and age estimation methods correlating growth with chronological age.

1.6 Difficulties with the Scientific Approach

Although the scientific approach has seemed promising for solving the age estimation problem, it is prone to difficulty and inaccuracy on many levels. As well as complex aspects of biological variation affecting accuracy, there are controversies to address concerning radiation and consent which together raise important ethical concerns [158, 217]. These issues have resulted in particular opposition to DAE in asylum seekers [195, 196, 217] and it is important to be aware of the risks which are implied. More fundamentally, but more difficult to understand without specialist knowledge, is the level of accuracy available in DAE and how it is presented by DAE practitioners. While observing that there is no better method of estimating age around the 18 year-old threshold than DAE, the level of inaccuracy that is acceptable to its practitioners and whether it should be done at all has been seriously questioned [7, 197, 198].

Medical or any type of intrusive examination is not preferential in the guidelines but some countries do employ a physical examination for age estimation purposes. For example, the Tanner five-point scale for the rating of sexual development has been advocated [6, 199]. The data for this method, categorised according to bodily changes in appearance during maturation, was collected from British children in the Harpenden Growth Study in the 1930's [27]. The data does not necessarily reflect modern patterns. Having not been designed for age estimation, it is criticised for being inaccurate when used for this purpose especially in relation to diverse populations [199]. Lack of reliability and intrusiveness detract from this method. Moreover, Tanner himself criticised the use of his system for age estimation, stating that the Tanner scales were not designed to be used for estimating chronological age but designed for estimating development or physiological age for medical, educational, and sports purposes where chronological age is known. He regarded its use for forensic purposes as "wholly illegitimate," and made clear its unreliability in age estimation [200, 201].

It is difficult to relate growth data from a group to a single individual in an attempt to determine age whether it be for skeletal or dental age estimation. The interrelationships between somatic, sexual, skeletal, and dental maturity are complex. Heavier children, for example, grow faster, mature earlier, and have advanced bone ages and earlier epiphyseal

union [202] . Such children have been shown to be advanced in their dental development but this is a less significant relationship. Although less affected by environmental factors, such as nutrition than skeletal development [202, 203, 204], it would seem reasonable to suggest that it would be similarly influenced [205]. In support of this, a study on Southern African children found significant differences in dental development related to different BMI statuses [206]. Dental development is accelerated in girls with early menarche, and steroid hormones of gonadal and adrenal origin have been implied in the relationship between sexual maturation and dental development [207, 208]. A secular trend of earlier menarche may also be linked with earlier maturation of the teeth [209]. Ethnic variability in sexual maturation [210] is a further consideration. In boys with constitutional delay of growth and puberty (CDGP), delay of onset of puberty was associated with delay in dental maturation [211], agreeing with Garn et al who noted sex-steroid dependence on late-forming teeth [202], but the literature concerning hormonal effects, including the timing of dental development in syndromic conditions, is very sparse.

Radiation

Exposure to x-ray radiation should always be kept as low as reasonably achievable. For a DPT taken for DAE, the dose is of the order of 26 microsieverts [212.] This could be considered equivalent to 4.5 days in the UK and 1.5 days in Cornwall where background radiation is higher than the national average of about 2.7 millisieverts a year [213]. The radiation risk of a DPT is claimed to be about that of half a long-haul air journey [214] or a vanishly small risk [215].

In 2018, the Ionising Radiation (Medical Exposure) Regulations (IRMER) 2017, UK Statutory Instruments 2017 No. 1322 Regulation 11, came into force, is applicable to England, Scotland and Wales, and incorporates some changes relevant to DAE. Previously termed medico-legal exposure, IRMER now defines this as “non-medical imaging exposure” meaning any deliberate exposure of humans for imaging purposes where the primary intention of the exposure is not to bring a health benefit to the individual being exposed. The regulations regarding non-medical imaging exposure are as follows:

Section 3(f): *These Regulations apply to the exposure of ionising radiation in England and Wales and Scotland - to individuals undergoing non-medical imaging using medical radiological equipment.*

And Section 11(1)(e): *A person must not carry out an exposure unless - in the case of an exposure falling within regulation 3(f) (non-medical imaging), it complies with the employer's procedures for such exposures.*

The regulations therefore permit radiographs for legal purposes assuming the "employer" has a valid and ethical protocol for the procedure.

In 2016, the Immigration Court stated that the danger to an individual arising from exposure to x-rays is wholly outweighed by the intended benefit of a contribution to the evidence used in age assessment; and that it is likely to be unreasonable for a young person whose age is disputed to refuse to undergo the process, or for a refusal to be entered on his behalf. It was said that generally speaking a dental tomograph should be ordered if a party seeks it and the earlier it is taken, the more likely it is to offer useful information [191]. Also in 2016, the Court of Appeal held that a claimant who argued that he had been incorrectly deemed an adult would have to agree to an age assessment by means of a dental x-ray in order to continue with his claim against the local authority [216].

The radiation risk, however small, can only be defensible if the method provides a reliable result.

The British Dental Association (BDA) has condemned DAE of asylum seekers as unethical and cite the use of x-rays as wrong [217]. The Faculty of General Dental Practitioners UK (FGDP (UK)) corroborate the stance of the BDA which is also shared by the Royal Colleges in the UK and advise that this practice goes against the FGDP(UK)'s radiography guidelines [218]. The FGDP(UK) also advises that many dentists may not be indemnified for such procedures which may nonetheless still be happening in the UK at the request of public authorities.

Criticism of the non-therapeutic basis for taking a DPT is emphasised but this must not cloud the fundamental issue of accuracy in DAE. In Australia, a ruling against radiography followed the case of many Indonesian asylum-seeking children who were wrongly assessed

as adults based on hand/wrist radiographic examination [219, 220]. However, hand/wrist radiography is still recommended as "the gold standard" in skeletal age estimation despite alternatives such as MRI or ultrasound [221].

MRI use avoids radiation and is being investigated for use in DAE [140]. MRI knee examination is carried out for age estimation in Sweden but has been noted for potentially causing difficulties for traumatised children because of the noise generated and confinement in a small space while the scan is taken [61]. The issue of accuracy still prevails when considering using the knee as an age indicator at the 18-year-old threshold.

Consent

Valid consent is essential for any intervention. Consent can only be obtained from a person if they are competent to give it and this ability may not be easy to confirm. In the case of UASC, an advocate who understands the consent procedure should be present. Translators may also be required, emphasising the need to ensure understanding. Any health professional involved in age estimation is required to ensure that ethical considerations for the individual under scrutiny are paramount.

The General Dental Council (GDC) advises that patients should be informed, and their understanding recognised, of why a particular treatment (or investigation) is necessary and appropriate for them; the likely prognosis (or result); and what might happen if the proposed treatment (or investigation) is not carried out [222]. Enough information, and a reasonable amount of time to consider that information, must be given in order to make a decision. The information should be given in a format that can be easily understood, and questions encouraged from carers or friends if the individual has communication difficulties. Withdrawal of consent, and dignity and privacy are also important aspects of the consent process.

Written signed consent is regarded as best practice and has been advocated by professional bodies and forensic radiographers [221] but does not necessarily demonstrate that valid consent

has been obtained [223]. A consent form should be supported by contemporaneous records that show the communication which has taken place.
Cultural issues such as dress codes must be respected and there are differing cultural attitudes to exposing parts of the body, some females wishing only to be examined by female practitioners. In some cultures exposing the foot or knee are sensitive issues which raise ethical concerns for knee examination in age estimation [61].

An important difficulty is that of requesting consent for a procedure that can only provide an estimate of age within a range of several years. UASCs may trust that their true age will be revealed when, in fact, the age estimation may suggest they are at an unexpected side of a significant age threshold. Individuals may believe that withholding consent for age estimation will be detrimental to them in Court. However, the European Asylum Support Office states that an application for asylum cannot be refused on the basis that consent is not given for a medical examination. In this situation, the child should not automatically be considered an adult and no consequences should arise from their decision [193].

Accuracy

DAE relies on observation and allocation of TDS. Observer bias, unconscious or otherwise, which could affect accuracy, has to be considered. Machine learning to automate allocation of TDS, and diminish observer bias, has been suggested [224].

At the heart of DAE is the RDS. This should match the growth characteristics of an individual. Ideally, but impossibly, the RDS should reflect all socio-economic, health, nutrition, growth, and ethnic factors affecting growth variation in a population.

Third molar TDS in any individual are very likely to fall within the age ranges in large RDSs. However, eight year age ranges for third molar TDS are not unusual. These large ranges inevitably lead to lack of accuracy in DAE and this remains the most important criticism of DAE. Statements such as the possibility of error of approximately plus or minus 2 years for third molar assessments for 95% of the population have raised understandable concerns [225].

The age range for TDS may not be well represented in small RDS and can be expected to increase with larger samples or samples with greater influence of factors affecting development. Age ranges of several years around the 18-year-old threshold greatly compromise accuracy.

DAE methods involving calculations based on dental development must offer suitable relevance to individuals in terms of the reference data. Statistical tests must be applied in such a way that is fair to an individual and does not obscure features in the data such as possible wide age ranges of dental development. Rather than a response with, for example, a range of 17.5–18.5 years, it may be more informative to state the probability, or risk, of that individual having reached the 18-year-old threshold [226] but it is important to explain the range of possible error. It is especially important to bear in mind that the chances of being a certain age are derived from a group and when estimating the age of an individual this is no more than suggesting the odds of how old they are and has to rely on chance. There is no certainty that an individual's age will correspond to the average age indicated by the reference data or be within the age group demonstrated by, for example, 90%, or any other chosen range, of the reference group. Bayesian statistics are complex, require specialist statistical knowledge, and their use in DAE has only been described by a few proponents [229, 227, 228]. This approach is still prone to the insurmountable difficulty of assigning an age to an individual using widely varying group data, the data itself not necessarily even appropriate. The statistical arguments have been reworked and scrutinised but a solution for determining age thresholds is still unclear [229].

As stated in the Upper Tribunal Court, statistics may be more useful to decision-makers at the far ends of the scale, by showing the plausibility or implausibility of a proposition, than in the middle of the scale where they purport to show the likelihood of the correctness of a plausible proposition [191]. While accuracy must be tempered with the impossibility of providing an exact age, proof of attainment of an age threshold is the standard required to justify a fair outcome.

DAE studies report accuracy in terms of how closely a studied population relates to an already published RDS. These studies cannot alter the fact that any one person may show development at any point within or even outside a range of the reference data.

The reliability of age estimation has been shown to improve when a hand/wrist assessment is combined with DAE [221]. Combinations of different age estimation methods might be interpreted as advantageous but it does not necessarily follow that combining inaccurate methods lead to a more accurate final result.

In 2019, a case heard in Belgium involving an asylum seeker from Guinea who claimed he was 17 years old was given an age estimation of "26.7 years with an SD of 2.6 years" which was overturned by the judge who ruled that the claimant could be 17.5 years of age according to the results of individual tests [230, 231]. These included examination of wrist, clavicle, and dental radiographs. The judge showed that amalgamation of the results did not assist with the age estimation. It was concluded that the age given from the teeth and wrist could place the claimant at his stated age. Based on the dental radiograph, the expert assessed the claimant's age as 22.6 years with a SD of 1.9 years, stating a 96% chance that the claimant was over 18 years of age. The judge pointed out that this shows that there was a 4% chance that he was under the age of 18.

It is important to note the following words of UTJ Ockelton in 2016 [191] : "the description of dental maturity by reference to the Demirjian stages appears to be widely-used and useful. It is of very limited use for age assessment when all or very nearly all teeth have reached Stage H and the fact that all teeth have reached Stage H is not of itself sufficient to be a guide to whether a person is or is not over the age of 18". In the same judgment, UTJ Ockelton stated that none of the three MMMs had yet been sufficiently examined to enable it safely to be said that it is diagnostic of age [191]. It was also stated that the relevance of ethnic background to the progress of dental maturity is not yet clear [191].

In a Judicial Review in 2017, the difficulties with assigning an age to an individual based on third molars using Demirjian TDS and MMM Stages, in terms of reference samples, possible ethnic differences, and statistical inferences, were scrutinised and found to be unreliable [232].

DAE, however, is an undeniably important technique in many situations. Establishing a legal age threshold with its attendant consequences is in great contrast to its use in age estimation as an aid to identification or investigation of skeletal remains. As noted by UTJ Ockelton [191], ethnicity is a factor in DAE which is unclear. The evidence for ethnic difference in dental development will be reviewed in the following section.

1.7 The Timing of Third Molar Development and Population Differences

Ethnicity

Ethnic difference can never be considered a straightforward variable since it is a naive belief that ethnic groups are genetically distinct [207]. Mixed ethnicity has been an entrenched feature of mankind throughout the millennia and the fastest growing ethnicities in the UK are now defined as the mixed groups [233]. However, if presented with ethnic choices, people tend to feel part of a group and are comfortable with self-assignment of an ethnicity [234].

All people alive today can trace their common ancestors to African origins, with the fossil record consistently pointing to this continent as the ultimate origin of all human beings [235, 236]. Genetic studies have shown that many Africans today, including many who have lived outside Africa for generations, are directly related to an ancestor originating within the last 150,000 years, and whose mitochondrial DNA (mDNA) we all share [237]. The human gene pool has become infinitesimally mixed but mDNA is retained almost completely intact as it passes from generation to generation in the maternal line. By investigating the whole DNA profile of Native Americans and White Americans who believe they can trace their ancestors genealogically back to European settlers, firmly held beliefs about family history and ethnicity were shown to be generally not as reliable as families and individuals believe [238]. In generations spanning the far distant past, many liaisons have ensured the incorporation of DNA from people of many groups. Ethnicity can never be considered finite. However, accepted ethnic groups such as Caucasians and Black Africans do show differences which may be of importance and should therefore be recognised. Examples are the existence of sickle cell disorder, or the increased likelihood of prostate cancer, which occur in people of African ancestry. Knowledge of these susceptibilities allows specific action to be taken. Sometimes a disadvantageous trait is balanced by the coexistence of an advantageous one, such as the gene for sickle cell conferring immunity to malaria, and it is genetic characteristics such as these which has contributed to the survival of human groups in different geographical locations and environments [239].

An age estimation result depends on the relevance of the RDS to the individual whose age is questioned. An RDS which matches the growth characteristics of an individual should ideally take into account as many factors as possible which cause variation.

The effect of ethnicity on DAE

The effect of ethnicity on DAE is a subject of debate and has been dismissed in the past [19, 241, 242]. Ethnic differences in TMA and hypodontia, which are both associated with delay in dental development, have been reviewed earlier in this chapter. TMA is significantly less prevalent in those of African ancestry compared to Caucasians. The possible effect of this in DAE will be discussed following a review of the timing of dental development which is, of course, of fundamental importance in DAE, together with the evidence for associated population differences.

In "the ABFO (American Board of Forensic Odontology) study", Demirjian's method was applied to 823 males and females aged between 14.1 and 24.9 years [240]. Caucasians represented 80% and only these were used in computations. Third molars were the most variable teeth and an SD of about two years was found at each TDS. Left and right symmetry was present in 78% of cases and 54% showed third molars at the same stage in maxilla and mandible. Development was significantly earlier in males than in females. No difference was found in those of Black ethnicity and White ethnicity although it was observed that this could be because of a limited sample size. The probability of an individual being at least 18 on the basis of third molar formation was calculated. If a lower third molar root was completely formed, apices complete and the periodontal ligament of uniform width (Stage H) it was deduced that the probability of being 18 or older is 90.1% for males and 92.2% for females.

The ABFO Study [240] also stated, regarding third molars, that "if a subject presents with a grade A through D there is little likelihood that he or she is 18 years of age… if the root apices are closed (Grade H), one can be reasonably confident that the subject is indeed at least 18 years of age. This leaves three ambiguous stages, grades E, F and G. It is essentially a coin toss (50:50) whether a subject with one of these grades is younger or older than 18."

Lewis and Senn [164] acknowledged that different American populations demonstrate different rates of third molar development but concluded that, although more data was needed, the fact that an individual having third molars at Demirjian stage H had very likely reached age 18 demonstrated the validity of this technique for determining legal age in the United States.

Combining worldwide data, the probability of being over or under 18 based on third molar development has been calculated by Liversidge and Marsden [241]. It was concluded that, for all populations, if the third molar has its apex half or fully complete, age is more than likely at least 18. A single individual from any ethnic group was regarded as not significantly different from one in any other group. Features of the reference sample such as size, range and age distribution were stated to be more important than ethnicity or geographic group. It was suggested that population specific studies are not required for DAE. The view that populations can be pooled for DAE purposes, and that population-specific reference data is probably unnecessary, has been supported by studies including Sub-Saharan African populations together with European, Malaysian, Japanese and Bangladeshi populations [163]. When data from populations from Belgium, China, Japan, Korea, Poland, Thailand, Turkey, Saudi-Arabia, and South India were compared, the conclusion was that an RDS from Belgium provided an overall better reference for individuals from all these populations than other published RDS [242].

Despite many studies claiming differences in the timing of dental development between non-African populations [240, 243, 244, 245, 246, 247, 248, 249] and suggested explanations including socio-geographic factors [250] as well as genetic influence, the consensus of opinion in the UK was, at least until the last few years, that ethnicity does not greatly influence the age of attainment of third molar TDS [215, 163]. This remains challenged by several studies summarised below.

Employing clinical examination of 990 East African males aged from 6 to 26 years, admitting that some of the 13-16 year-olds may have falsified their age downwards, it was stated that the probability of a boy aged 14 having all his third molars erupted is 1 in 10; at 16 years 1 in 2; at 18 years 3 in 5 while above 21 years it is 4 in 5 [251]. Concluding that third molar eruption occurred at a much younger age than in European boys, this agreed with an earlier study [252] where Philippinos and Zulus began third molar eruption at 13; and most had a full set of permanent teeth at the age of 20 while third molars in most White Americans were still absent at age 18.

In a clinical study of 3,423 White Bostonians with ages ranging from 13 to 22 years, the median age of emergence of the upper third molar was 20.5 years in both males and females, while the lower third molar emerged at 19.8 and 20.4 years respectively [123]. These individuals were selected as having intact first and second molars in order to avoid the effect of earlier emergence of third molars as a result of loss of molars anterior to them. The findings were compared to the East Africans in the above study [251] who were in advance of the Bostonians, being 2.5 years ahead in the 13-16 year-old age group, and 1.5 years in the older age groups although it was again pointed out that the younger group may have been older than they claimed, and the older group drawn from many parts of Africa.

A clinical study by Garn et al of 1,951 subjects found that clinical eruption of third molars in Black Americans was significantly advanced compared to Americans of European descent [253].

Following these studies, third molars were clinically examined in a study of 1,343 African and 1,092 Asian students in Kenya aged 13 - 23 years [254]. In Africans, lower molars emerged at 17.6 - 18.3 years followed by upper molars at 18.5 - 18.9 years, and in Asians, these results were 19.9 - 20.3 years and 20.7 - 21.0 years respectively. Differences between males and females were not significant. More accuracy was claimed compared to the East African and Bostonian studies above and, in 13-20 year-olds, African males were shown to be about 1.5 years ahead of Bostonian males; and Asian males about 0.25 years behind.

Clinical observation of third molars in 258 Nigerian adolescents found the average age at clinical eruption was as young as 13 for females and 15 for males and that all third molars had erupted by age 19 [255]. Lower molars erupted before upper molars in both sexes. The authors regard a fibrous diet and well-developed masticatory apparatus as important for promoting jaw growth and consequent space to facilitate third molar eruption. No lack of eruption was observed in 222 rural Nigerians aged between 31 and 80 years. A later clinical study of 1,071 11-21 year-old Nigerians reported similar results [256].

A small clinical study of third molars in 155 White British and Black British males aged between 14 and 18 years in a Young Offenders Institution, showed a strong association (Chi square test, $p = 0.019$) between ethnicity and erupted third molars at age 16.75 to 18.25 years with the Black British group being ahead of the White group [257]. Even making an allowance

for third molar agenesis of 9% in White British and 1.6% in Black British taken from previous studies and tending to narrow the difference found, and excluding dentitions with molar extractions, Black British 17-year-olds were significantly ahead of White British 17-year-olds in third molar eruption. As one or more clinically erupted third molars were seen in 68.4% of the 17-year-old Black British group, the average age for third molar eruption in Blacks was shown to be less than 18. If any of these third molars, or even unseen impacted ones, were at stage G or H, i.e. the stages equated with clinical eruption [68], then according to Liversidge and Marsden [241], the individuals would be, on the balance of probabilities, at least 18. As they were all known to be under 18, this raised concerns and highlighted the need for further radiographical investigation of this possibly very important factor in DAE.

In a radiographic study, third molar developmental stages were reached at least a year earlier in Black Americans compared to White Americans, and earlier in males than females. The likelihood that an African American having fully developed third molars is at least 18 was stated as 93%, and 90% for Whites [258]. Black South Africans have been found to be significantly advanced in third molar development compared to Cape Coloureds and White and Bangladeshi children in the UK [259]. In a study of relative calcification of teeth in 687 Africans, third molars in this sample were found to be markedly advanced compared to those of 329 French-Canadians [260].

Harris noted that clinical studies, published in 1942 and earlier, which showed earlier tooth eruption in Black ethnic groups both in Africa and America were met with some criticism based on wrongful preconceptions that Caucasians were considered to be "faster-growers" [207]. Using Moorrees TDS, Harris found that Black Americans tend to achieve each mineralisation stage of lower third molars appreciably faster than their White American counterparts [207]. A distinct difference in the tempo of third molar development between the two groups was also observed as Black Americans were more ahead of White Americans at the early and late stages of tooth formation. Harris also observed that faster tempos of growth in Sub-Saharan Blacks, girls in particular, and geographically diverse populations from the African diaspora compared to Whites is not controversial, particularly with regard to bone age [207].

A study comparing third molar development in Sub-Saharan African (n= 653 males, 721 females), Japanese, Malaysian, White-European UK (n= 430 males, 605 females), and

Bangladeshi UK populations aged between 10 and 25 years, with the sample not uniformly distributed by age, and Moorrees stages, showed that the Sub-Saharan African males and females were slightly ahead in third molar development compared to the other groups [163]. The difference was regarded as insignificant for DAE because of little difference in the 95% confidence interval for estimated age which can be as much as nine years. Uniform age distribution and a Bayesian approach with condition on age rather than relying on mean age at each TDS to avoid age mimicry was recommended. Inter observer variation due to the study locations being in different parts of the world and lack of information about socio-economic status were cited as possibly leading to difficulties with reliable ethnic comparisons.

In the first study involving an Afro-Caribbean population in Trinidad and Tobago, almost all Demirjian TDS, that is, 97% or 171 out of 176 TDS assessed, were attained earlier in Afro-Trinidadians (n=878 DPTs) compared to a UK Caucasian RDS [261]. For lower third molar TDS the mean age difference was approximately 1.5 years. This study demonstrated an ethic difference in dental development and showed that by using an Afro-Trinidadian RDS, more accurate DAE could be carried out for that specific population. The data confirmed the clinical impression held by colleagues that dental development occurs earlier in Afro-Caribbean children and adolescents compared with Caucasians. It was also noted that the results appeared logically consistent when compared with similar findings between Black South African and German Caucasian subjects, where the former were up to two years ahead in dental development [262], because the Afro-Trinidadian heritage is mixed African and Caucasian.

Because of its reliance on a French-Canadian RDS, the validity of Demirjian's method [65] has been questioned. The method has been shown to cause overestimation or underestimation of chronological age in many studies around the world including in British, Belgian, Finnish, Swedish, Spanish, Malaysian, Dutch, Turkish, Pakistani populations [263]; Former FYR Macedonian [264], Indian [265], and Australian samples [226] suggesting the need for population-specific RDS. Studies of this kind compare a test population with the RDS of a well-known method and not different population groups at the same location. However, a recent study of six population groups in the Netherlands using the Demirjian method, but in comparison with a Dutch group, found that children of African ancestry were advanced in dental development compared to other groups [266].

1.8 Importance of hypodontia and TMA in DAE

Conventional DAE using a DPT addresses the lower left quadrant. When a lower left third molar is missing or there is hypodontia, the antimere is substituted in order to allocate a TDS. This approach ignores any delaying effect of TMA and hypodontia on the timing of dental development. TMA and hypodontia in other quadrants, another sign of possible delayed dental development compared to individuals with a complete dentition, are also disregarded.

DAE studies, often not having included the third molar for scrutiny in any case, ignore the effects of TMA, which may inevitably exist in any sample, on the timing of dental development. The question arises as to whether TMA is causing delayed development in a proportion of reference samples and affecting the accuracy and outcomes of DAE.

In summary, hypodontia and TMA potentially affect DAE with a risk of overestimation of age in those with developmentally missing teeth.

Measuring asylum seekers' development against standards derived from British children may be inappropriate [267]. Ethnicity is now regarded as deserving important consideration and the need for research has been acknowledged. As the majority of UASC are of African origin, there is a particular need to understand the timing of dental development in people of African ancestry.

In summary, early clinical studies demonstrated earlier tooth eruption in African populations compared to populations of White ethnicity. Following later radiological studies, a consensus of opinion was established that ethnicity was insignificant in DAE. However, the literature persists in the suggestion that dental development in those of Black African ancestry may occur earlier compared to those of White ethnicity. If this is so, there is a risk of overestimating the age of the majority of UASC, because of their African origin, with consequent injustice, if RDS from White ethnic groups are employed for DAE. It is therefore important to further understand the relevance of ethnicity in DAE.

Chapter 2

Aims and Hypotheses

2.1 Aims

Understanding the timing of development of the third molar is essential to DAE at the 18-year-old threshold. Many age-disputed cases involving DAE at the 18-year-old threshold, which relies only on third molar development, concern UASC from African countries. The literature suggests that development of the third molar may occur earlier in Black African populations compared to populations of White ethnicity from whom data for DAE has been employed. It is naïve not only to assume that ethnic groups are well-defined, but also to ignore differences that do exist. Differences which could lead to injustice for any ethnic group or individual of any ethnicity in DAE deserve to be understood. Considering the scarcity of radiological studies of dental development in those of Black African ancestry and the risk that age could be overestimated using data from subjects of White ethnicity, further investigation of possible ethnic differences in third molar development is the essential focus of this study.

Differences will be investigated by direct comparison of age at assessment of TDS without recourse to calculation of chronological ages from dental ages as is required for DAE. Comparison of mean ages for TDS has been the basis of numerous publications [289, 268, 269, 270] and this unambiguous approach was agreed for the comparison of the two ethnic groups in the present study.

The principal aims of the research are to:

1. Establish if there is a demonstrable ethnic difference in dental development, focusing on the third molar, in children and young adults of Black British or other Black ethnicity and White British subjects living in the same area of the UK.

2. Establish if any such difference is the same in males and females within and between ethnic groups.

The literature suggests that TMA is less prevalent in those of African ethnicity compared to those of White ethnicity. Hypodontia (up to five developmentally missing teeth excluding third molars) has been associated with slower development of the dentition so this, and TMA, are features with potentially important repercussions for DAE. The prevalence of hypodontia, TMA, and comparison of third molar development in subjects with and without developmentally missing teeth will therefore also be investigated.

Further aims are therefore to:

1. Establish if there are significant differences in the prevalence of developmentally missing teeth, particularly TMA, between Black British or other Black ethnicity, and White British ethnic groups.

2. Establish if developmentally missing teeth affect the timing of third molar development.

And finally,

3. To consider the results of the research in the context of improving accuracy in DAE.

2.2 Hypotheses

The timing of third molar development

The null hypothesis is that the age associated with defined third molar development stages in UK subjects is the same in Black British and White British ethnic groups.

Third molar agenesis

The null hypothesis is that TMA is the same in Black British and White British ethnic groups.

Hypodontia

The null hypothesis is that the prevalence of hypodontia is the same in Black British and White British ethnic groups.

Hypodontia, TMA and DAE

The null hypothesis is that hypodontia or TMA do not affect the timing of dental development.

Chapter 3

Materials and Methods

3.1 Sample Requirements

To test these hypotheses, the availability of a suitable sample had to be considered. The King's College Dental Institute representing Guy's and St Thomas' NHS Foundation Trust (GSTT) serves an ethnically diverse population and it was anticipated that the large proportion of patients of African ancestry in the local area would facilitate the intended comparison. To collect suitable dental data, one DPT for each subject was required. An age range of 6.00 - 23.99 years allowed investigation of all the developmental stages of third molars from commencement of enamel formation to completion of root apices and be relevant to age estimation at the 18-year-old threshold. To ensure the study was as robust as possible, within the framework of ethics considerations, the sample was designed to have an even age distribution with specific inclusion and exclusion criteria.

3.2 Ethical permission

Ethical permission for this anonymised, cross-sectional, observational, retrospective study of existing dental radiographs was granted via the Integrated Research Application System (IRAS) from GSTT and the Regional Ethical Committee in Edgbaston, Birmingham (Ref. No. 18/WM/0215), the Health Research Authority (HRA) and Health and Care Research Wales (HCRW) with IRAS ID 239922 for a study titled "An evaluation of dental development in UK subjects of diverse ancestry" and sponsored by GSTT/King's College London. The application process was led by me with assistance from GSTT.

The GSTT Romexis® database holds all radiographs taken of patients attending the King's College Dental Institute and provided the DPTs for this study. The GSTT Romexis® database

dates from 2005 until the present day and by January 2020 contained approximately 48,000 DPTs. The DPTs were taken for diagnostic or treatment-planning purposes, largely by referral, and therefore it must be accepted that the intended DPTs for this study are not representative of ideal dentitions, nor of the general population as a whole, and may be termed a convenience sample. As all radiographs were taken with consent in the past, no consent from participants was necessary for this retrospective study.

At the outset of the research, the intention was to study a sample with an age range of 12.00-23.99 years of age to investigate third molar development around the 18-year-old threshold Preliminary results presented after the first year of the study showed significant ethnic differences in the later stages of third molar development. This prompted an amendment which increased the age range to 6.00-23.99 years of age so that the whole time span for third molar development could be investigated

3.3 Ethnicity

King's College Dental Institute is situated in central London, in the Borough of Southwark. Patients are therefore drawn from the local area of South London and the surrounding region as a result of the Institute's role as a referral centre. Southwark has a richly diverse ethnic community. While the proportion of White British residents was 40% in the 2011 census, Southwark had the largest Black African population in the UK (16.1%) and more than a quarter (27%) of residents identified as "Black" [271]. The GSTT Romexis® radiographic database therefore holds valuable information about a British population of diverse ancestry. Questions relating to the suggestion that geographical location or widely-differing socio-economic and nutritional factors are responsible for any differences that may be observed between different ethnic groups are minimised.

Giving further insight into demographics, the 2011 Census recorded 1,904,684 residents who identified as "Black/African/Caribbean/Black British", accounting for 3% of the total UK population [272] in contrast to the much larger proportion in Southwark. This was the first UK census where the number of self-reported Black African residents exceeded that of Black Caribbean residents [273].

Many who report Black or Black British ethnicity will have had British ancestors for many hundreds of years while others will have descended from more recent migrants or even have once been migrants themselves. The great majority of migrants arrive in the UK for employment, education, or family purposes. Migration applies to all ethnic groups with many White British subjects being born outside the UK or living in other countries during their lifetimes. In 2018, 36% of London's population were migrants. While 12% of these were born in non-EU countries, only 3% were of African origin. Furthermore, only 4% of African migrants were aged 0-15 years, 10% were aged 16-25 years, and this represents about 80,000 people in the whole of London [274]. In the Borough of Southwark, in the 2011 census, 15.5% of a total population of 288,283 people were born in Africa. Of the total Southwark population, of all ethnicities, 22% were aged between 8 and 24 years of age [275].

Asylum seekers in receipt of social welfare support have been mainly housed away from London and the South East and numbered around 45,000 in the UK at the end of June 2019, with 61% of that number having lived in the UK for more than 15 years. Of the approximately 26,000 refugees resettled in the UK since 2010, 19% were nationals of sub-Saharan African countries, 74% were nationals of Middle Eastern countries, and the remaining 7% were from the rest of the world. Only 0.06% of these asylum seekers and 0.01% of resettled refugees live in London [276].

In the UK, for censuses and other official data, ethnic information is collected by asking individuals to select from categories that may include nationality (e.g., Chinese, Indian, British), broader geographical or ancestral categories (e.g., African, Asian, Arab), colour (e.g., White, Black), and combinations of these ('White Irish', 'White British'), including explicitly 'Mixed' categories (e.g., 'White and Black Caribbean') [277, 278].

Concerns could be legitimately raised about the assignment, including self-assignment, of ethnicity. It is well understood that ethnicity is difficult to establish and that some individuals will intentionally state a misleading ethnicity. However, on registration at GSTT, patients complete a registration form and are given the opportunity to record an ethnicity which they feel is personally appropriate. The ethnic categories relevant to this study which are specified on the registration form are White-British, Black-British, Black-Other African, Black-Caribbean and Black-Any Other. Sometimes a country-specific ethnicity is recorded.

3.4 Age

Although it might seem that the only way to be sure of age is to see a birth certificate, even these can contain errors and it is possible that a document may be intentionally false. The assumption is that very few patients, or their parents, are uncertain of their date of birth or report it incorrectly. It is true that in many parts of the world, birth often goes unrecorded [2] but this is not the case in the UK where official registration of a baby's birth must be done within 28 days. Birthdays are such a fundamental part of family and social life in the UK that a child or young person's date of birth is unlikely to be in doubt. Some other cultures regard birthdays as less important but knowledge of one's date of birth is essential for life in the UK.

While the numbers are, as explained above, very low, it is likely that at least a few of the subjects within the study sample have come to the UK as young migrants or asylum seekers. This is no reason to believe that their age has been falsified. It must be accepted there may be individuals in the sample who will have given, unintentionally or otherwise, a false date of birth. It seems far more likely that the vast majority of all subjects in the sample have provided an accurate birth date.

Clerical errors by reception or clinical staff can be made in transcribing personal data. This can cause incorrect information to enter study data regarding, for example, dates of birth and dates of radiographs, and therefore the calculated age. Similarly, other personal information such as ethnicity may be wrongly recorded in the patient records.

3.5 The Guy's and St Thomas' NHS Foundation Trust Romexis® Database

Planmeca Romexis® is claimed to be the most powerful dental software platform in the world[279]. Figure 11 shows an example of a DPT viewed with Romexis®.

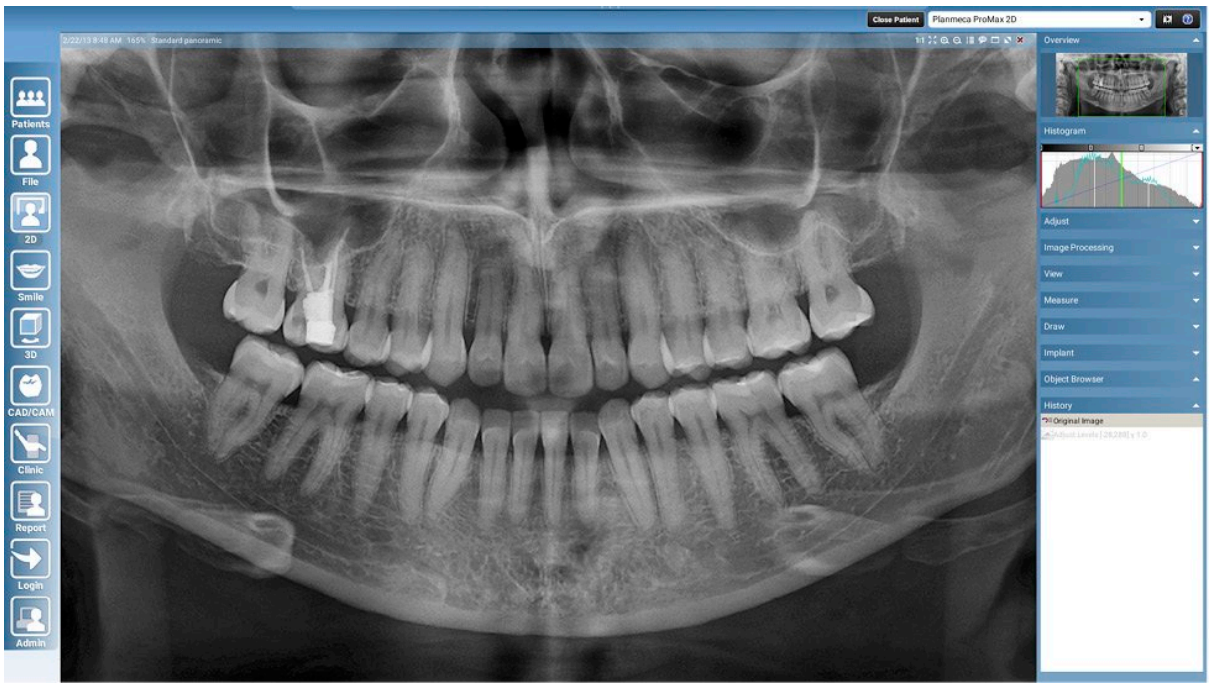


Figure 11. Example of a DPT viewed using Romexis® [280] (showing a fully developed permanent dentition with missing third molars and UR6 with root canal filling). (Permission for reproduction granted by Planmeca OY)

The Dental Institute at GSTT is a referral centre for specialist treatment, particularly for orthodontics and hypodontia. The DPTs show a wide variety of pathological features from dental caries to rare disorders affecting the teeth and jaws, some without a definitive diagnosis, and include hypodontia of varying severity, supernumerary teeth, impacted teeth or ectopic teeth, cleft palates, maxillo-facial trauma and surgical interventions, pathological conditions affecting tooth structure, and rarer conditions including a wide range of hereditary and acquired disorders. Figure 12 shows an example of a DPT of a patient with severe hypodontia.

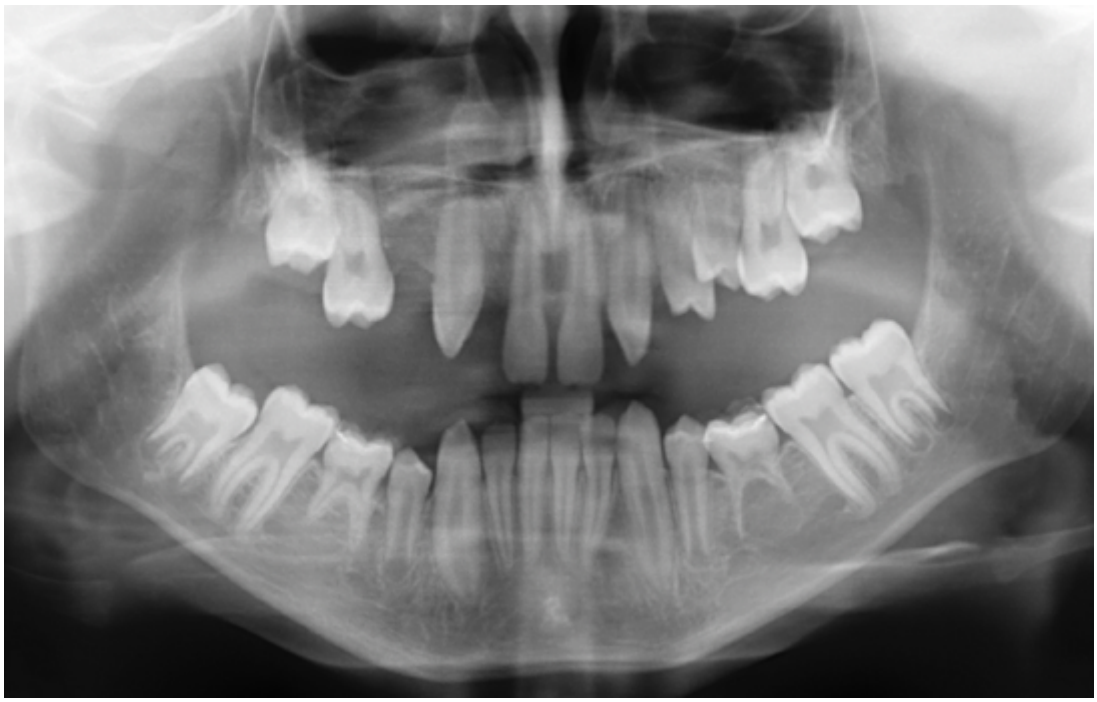


Figure 12. Example of a DPT demonstrating severe hypodontia (oligodontia) with developmentally missing upper lateral incisors, both upper right premolars, both lower second premolars, and no evidence of third molars. Their successors being missing, deciduous lower second molars are still present.

DPTs most often show all upper and lower teeth and their supporting bone but partial DPTs may be taken to avoid an unnecessary radiation dose to the patient. In this case, the DPT usually shows the left or right side of the dentition but be limited to any chosen area along the path of the x-ray beam. A partial DPT which may not include teeth is often ordered if views of the temporomandibular joint are specifically required.

Many patients have a series of DPTs taken during a course of treatment or to follow the progression of a disorder over several years.

Various tools are provided by the Romexis® software which can be employed to facilitate the allocation of TDS. These tools including enlarging the image, magnifying sections of the image (Figure 13), altering contrast and brightness, and measuring.

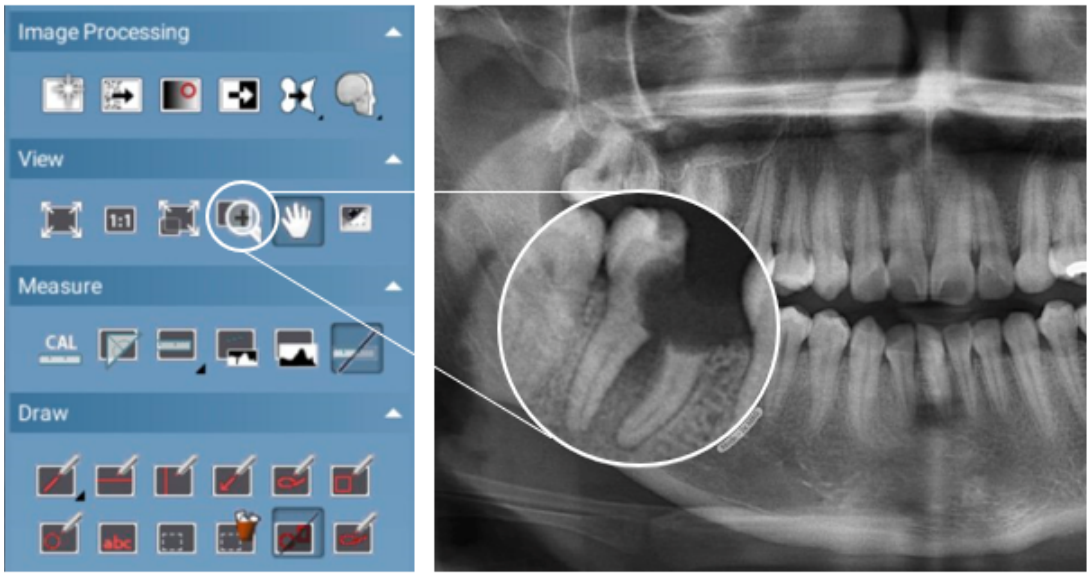


Figure 13. The effect of the Romexis® magnifying tool [280] (Permission for reproduction granted by Planmeca OY)

3.6 Sample Size Estimation

The sample size was first based on the 12.00-23.99 years age range and the suggestion that data from 50 DPT's, one for each subject, of males and of females in six-monthly age bands, for two ethnic groups, making a total of 4,800 subjects would form a very robust dataset [281]. This number increased to 7,200 when the lower age limit was changed to six years of age but had to be recalculated for the Black British group when it became clear that there were insufficient DPT's in the Romexis® database to satisfy the initial aim. The sample size estimation, as calculated by a statistician, is described below.

The power calculation for the study was based on comparing the mean tooth development age for two ethnic groups using independent samples t test. A difference of 0.75 years between the Black British and White British groups, with a SD of 1.32 was thought to be reasonable, giving an effect size of 0.57. Assuming an effect size of 0.57 for both males and females, 80% power and 5% level of significance, a total sample size of 50 in each half-yearly age band per ethnic group for both males and females would be required. With 50 male and 50 female subjects of each ethnicity in each 6-month age band between 12 and

23.99 years, the sample would consist of 24 age groups and two ethnic groups for both males and females, giving a total sample size of 4,800 subjects.

The sample size for each group, for males and females, White British and Black British, was therefore set at 50. This corresponds well with the 50 females and 50 males use in previous studies [282].

The power calculations were carried out using G*Power version 3.1.5.

With the amendment to the initial protocol, ethical permission was granted for an additional 2,400 subjects aged between 6 and 12 years. As previously, 50 subjects in each half-yearly age band of each sex and ethnicity was aimed for, making a total of 7,200 subjects in a sample spanning 6.00-23.99 years of age.

It became apparent as the study progressed that there were unlikely to be more than approximately 25 Black British subjects available in the Romexis® database for the half -year groups of males and females, with fewer being available in the younger age groups. The sample size was therefore reassessed with the assistance of GSTT Statistician, Mrs Fiona Warburton. Keeping the effect size at 0.57, with 80% power at the 5% level of significance but doubling the sample size in the White British group compared to Black British, gave a sample size of 75 White British and 37 Black British in each age group. As the numbers of Black British were still going to be too high, we calculated what effect size (0.70) could be detected with 50 White British and 25 Black British subjects. The mean difference observed between the ethnic groups is about 1 year, so an effect size of 0.7 would give a SD of 1.43.

The new aim was therefore to collect data for at least 25 Black British subjects in each half-year group. Effect size calculations showed that the power achievable in the sample is hardly affected with 50 White British and 25 Black British in each age band compared to 50 in each. Therefore, a target of >/=25 Black British subjects in each group was accepted. No surplus Black British subjects would need be discarded as having more than 25 in each group will not reduce the power.

Although it had to be accepted that the target would not be achievable for a few of the younger age bands, a new target was set at 3,600 White British and a minimum of 1,800 Black British, making a total minimum of 5,400 subjects.

3.7 Database Design

The data for this study was collected in a Microsoft® Office Access™ [283] database. Microsoft® Office Access™ (Access) allows data to be entered into custom-designed "forms" which then populate associated "tables" which are related to each other via a common variable, the "primary key", thereby forming a relational database. Data can later be retrieved from an Access database by designing a "query", drawing data from any of the tables. The results of the query can be exported to Microsoft® Office Excel™ (Excel) [284] or to suitable software, such as Stata® [285], for analysis. Calculated fields, such as age from the date of birth and date of radiograph, may be incorporated into queries so that this information is present in the exported data.

For this study, the Access database designed by DARLInG for dental data collection was recommended [286]. Additional fields were added to allow data collection for teeth present or missing on the right side as well as the left, and allocation of a dentition status reflecting the extent of developmentally missing teeth in each subject. This was necessary so that any ethnic difference in TDS could be analysed with respect to dental features such as hypodontia which themselves could have an ethnic bias. Separate Access forms were used to enter personal details, basic dentition data, Demirjian TDS, and MMM data.
Assessment of the eruption status of the third molars based on Olze Stages A-D, classifying the LL8 and LR8 [287], and Cameriere's third molar index measurements, were trialed. However, neither of these methods were employed in the study. It was conceded that assessing the Olze stages is difficult when restricted to a 2D radiological view. For Cameriere's method, it was found that the inside edges of the apices appeared too fuzzy and indefinite for accurate measurement to be made. The range of possible widths meant that significantly different ratios could be found for the same tooth. The adverse effect of apparent tooth foreshortening or lengthening according to its bucco-lingual angle was also apparent.

Other forms incorporated into the DARLInG design for Haavikko TDS, Moorrees TDS, and other parameters, were not needed but remained available as recommended. MMM data for PLV, RPV, and RCW, were also collected on separate forms but the results for these will not

be presented as COVID-19 restrictions prevented adequate intra rater testing for this aspect of dental data collection.

3.8 Establishing the Sample

Before adding any data to the Access database, an Initial List of subjects was compiled in Excel. Because of the large size of the sample, and to allow interim data analyses, establishment of the sample in Excel and dental data collection in the Access database were carried out in tandem and in many stages. Data collection for the final database containing data of 5,590 subjects was carried out over an approximately two-and-a-half-year period. Samples of up to 50 DPTs, taken for other purposes in the past, for groups of males and females in six-monthly age bands from 6.00-23.99 years of age, of both White British or Black British or other Black ethnicity as self-declared by each subject upon hospital registration, were found in the GSTT Romexis® radiographic database.

To do this, a search was made in Romexis® for all DPT's taken during a certain time period, generally one year, with dates of birth listed in chronological order. Subjects with an existing DPT were compiled in an Initial List created using Excel. Each row in the Initial List was given a unique identifying number (Study ID) representing the DPT. For each Study ID number, the first two letters of the surname, the sex, the date of birth (DOB) and date of the DPT, i.e., date of radiograph (DOR), were added. Data in this list allows subsequent finding of DPTs but remains unidentifiable and anonymised throughout the study.

Then the Electronic Patient Record (EPR), available for all GSTT patients on the same computer as Romexis® and containing their registration details, was consulted to confirm DOB and gender, and find the self-assigned ethnicity.

For the purposes of this study, self-assigned White-English, White-Scottish and White-Welsh were designated as White-British. Black-Ghanaian, Black-Ethiopian, Black-Somali, Black-Eritrean, for example, were designated as Black-African and therefore part of the Black-British group on the understanding that residence in the UK was established at the time of patient registration and British Nationality possible if not confirmed.

3.9 Self-assigned Ethnicities

Table 1 shows the self-assigned ethnicities of subjects with DPT's in the Romexis® database in the Initial List, 77 ethnicities in all, illustrating the wide ethnic diversity of patients attending GSTT. The Black British and White British groups are highlighted in the table to show how all the Black ethnicities are included in the former group and the White British, English, Scottish and Welsh included in the latter group.

Table 2, which is shown in two parts due to its length, shows the proportions of the different ethnicities in the first 10,000 subjects on the Initial List. This is representative of demographic spread of the whole sample.

Approximately one quarter of all subjects did not state an ethnicity. This varied according to the year of registration with fewer patients registering their ethnicity in recent years than in some of the earlier years after the Romexis® database started in 2005. In the first 10,000 subjects of the Initial List, 12% were Black British and 41% were White British (Table 2 Parts 1 & 2). Subsequently, the self-assigned ethnicity was not recorded unless it could be categorised as Black British or White British. Once there were enough subjects in the list to fulfil the White British component, it contained 14,954 subjects of whom 12% (11.95%) were included in the Black British group and 41% (40.68%) were White British. Many of these subjects were represented more than once in the list as they had more than one DPT in the Romexis® database and so, although associated with the demographic distribution for DPTs, not a true representation of the demographics of patients attending GSTT. Once the Black British sample had also been established, the Initial List contained 20,019 subjects, of which 16% (16.26%) were Black British and 39% (38.86%) White British.

Table 1. Self-assigned ethnicities in the Initial List

Self-Assigned Ethnicities (77)		
ASIAN-ANY OTHER	MIXED-ANY OTHER	WHITE-ALBANIAN
ASIAN-BANGLADESHI	MIXED-ASIAN/CHINESE	WHITE-ANY OTHER
ASIAN-BRITISH ASIAN	MIXED-BLACK/ASIAN	WHITE-BRITISH
ASIAN-CARIBBEAN/ASIAN	MIXED-BLACK/WHITE	WHITE-CROATIAN
ASIAN-EAST AFRICAN	MIXED-CHINESE/WHITE	WHITE-ENGLISH
ASIAN-INDIAN/BRITISH INDIAN	MIXED-OTHER UNSPEC	WHITE-FORMER USSR
ASIAN-MIXED ASIAN	MIXED-WHITE/BLACK AFRICAN	WHITE-GREEK
ASIAN-OTHER UNSPECIFIED	MIXED-WHITE/BLACK CARIBBEAN	WHITE-GREEK CYPRIOT
ASIAN-PAKISTANI	MIXED-WHITE/ASIAN	WHITE-GYPSY/ROMANY
ASIAN-SINHALESE	NOT STATED	WHITE-IRISH
ASIAN-SRI LANKAN	OTHER-ANY ETHNIC GROUP	WHITE-IRISH TRAVELLER
ASIAN-TAMIL	OTHER-ANY OTHER ETHNIC GROUP	WHITE-ITALIAN
BLACK-ALGERIAN	OTHER-ARAB	WHITE-KOSOVAN
BLACK-ANGOLAN	OTHER-CHINESE	WHITE-KURDISH
BLACK-ANY OTHER	OTHER-COLOMBIAN	WHITE-MIXED WHITE
BLACK-BLACK BRITISH	OTHER-ECUADORIAN	WHITE-OTHER UNSPECIFIED
BLACK-CARIBBEAN	OTHER-FILIPINO	WHITE-OTHER YUGOSLAVIAN
BLACK-ERITREAN	OTHER-IRANIAN	WHITE-OTHER/MIXED EUROPEAN
BLACK-ETHIOPIAN	OTHER-IRAQI	WHITE-POLISH
BLACK-GHANAIAN	OTHER-JAPANESE	WHITE-PORTUGUESE
BLACK-MIXED BLACK	OTHER-LATIN AMERICAN	WHITE-SCOTTISH
BLACK-NIGERIAN	OTHER-MALAYSIAN	WHITE-SERBIAN
BLACK-OTHER AFRICAN	OTHER-MIDDLE EASTERN	WHITE-TURKISH CYPRIOT
BLACK-OTHER UNSPECIFIED	OTHER-VIETNAMESE	WHITE-TRAVELLER
BLACK-SOMALI		WHITE-TURKISH
BLACK-SUDANESE	BLACK BRITISH GROUP	WHITE-WELSH
BLACK-UGANDAN	WHITE BRITISH GROUP	

Table 2 Part 1. Distribution of Self-Assigned Ethnicities in Initial List - first 10,000 subjects

Self-Assigned Ethnicity	n	%	
ASIAN-ANY OTHER	121	1.21	
ASIAN-BANGLADESHI	104	1.04	
ASIAN-BRITISH ASIAN	28	0.28	
ASIAN-CARIBBEAN/ASIAN	1	0.01	
ASIAN-EAST AFRICAN	3	0.03	
ASIAN-INDIAN/BRT IND	219	2.19	
ASIAN-MIXED ASIAN	7	0.07	
ASIAN-OTHER	5	0.05	
ASIAN-OTHER UNSPECIFIED	21	0.21	
ASIAN-PAKISTANI	119	1.19	
ASIAN-SINHALESE	1	0.01	
ASIAN-SRI LANKAN	12	0.12	
ASIAN-TAMIL	6	0.06	
BLACK-ALGERIAN	1	0.01	
BLACK-ANGOLAN	1	0.01	
BLACK-ANY OTHER	172	1.72	
BLACK-BLACK BRITISH	222	2.22	
BLACK-CARIBBEAN	230	2.3	
BLACK-ERITREAN	4	0.04	
BLACK-ETHIOPIAN	6	0.06	**BLACK BRITISH GROUP**
BLACK-GHANAIAN	10	0.1	Total 1207
BLACK-MIXED BLACK	10	0.1	Percentage 12%
BLACK-NIGERIAN	46	0.46	
BLACK-OTHER AFRICAN	442	4.42	
BLACK-OTHER UNSPECIFIED	19	0.19	
BLACK-SOMALI	38	0.38	
BLACK-SUDANESE	3	0.03	
BLACK-UGANDAN	3	0.03	
MIXED-ANY OTHER	78	0.78	
MIXED-ASIAN/CHINESE	3	0.03	
MIXED-BLACK/ASIAN	5	0.05	
MIXED-BLACK/WHITE	10	0.1	
MIXED-CHINESE/WHITE	11	0.11	
MIXED-OTHER UNSPECIFIED	8	0.08	
MIXED-WHITE/BLACK AFRICAN	50	0.5	
MIXED-WHITE/BLACK CARIBBEAN	171	1.71	
MIXED-WHITE/ASIAN	80	0.8	
NOT FOUND ON EPR/DPT TEST	5	0.05	
NOT STATED	2424	24.24	

Table 2 Part 2. Distribution of Self-Assigned Ethnicities in Initial List -first 10,000 subjects

OTHER-ANY ETHNIC GROUP	114	1.14	
OTHER-ANY OTHER ETHNIC GROUP	48	0.48	
OTHER-ARAB	24	0.24	
OTHER-CHINESE	143	1.43	
OTHER-COLOMBIAN	10	0.1	
OTHER-ECUADORIAN	5	0.05	
OTHER-FILIPINO	8	0.08	
OTHER-IRANIAN	8	0.08	
OTHER-IRAQI	10	0.1	
OTHER-JAPANESE	2	0.02	
OTHER-LATIN AMERICAN	18	0.18	
OTHER-MALAYSIAN	4	0.04	
OTHER-MIDDLE EASTERN	12	0.12	
OTHER-VIETNAMESE	14	0.14	
WHITE-ALBANIAN	3	0.03	
WHITE-ANY OTHER	496	4.96	
WHITE-BRITISH	3724	37.24	
WHITE-CROATIAN	1	0.01	
WHITE-ENGLISH	316	3.16	
WHITE-FORMER USSR	14	0.14	
WHITE-GREEK	4	0.04	
WHITE-GREEK CYPRIOT	6	0.06	
WHITE-GYPSY/ROMANY	3	0.03	
WHITE-IRISH	55	0.55	
WHITE-IRISH TRAVELLER	2	0.02	**WHITE BRITISH GROUP**
WHITE-ITALIAN	2	0.02	Total 4048
WHITE-KOSOVAN	11	0.11	Percentage 41%
WHITE-KURDISH	5	0.05	
WHITE-MIXED WHITE	2	0.02	
WHITE-OTHER UNSPECIFIED	82	0.82	
WHITE-OTHER YUGOSLAVIAN	1	0.01	
WHITE-OTHER/MIXED EUROPEAN	76	0.76	
WHITE-OTHER UNSPECIFIED	3	0.03	
WHITE-POLISH	6	0.06	
WHITE-PORTUGUESE	27	0.27	
WHITE-SCOTTISH	3	0.03	
WHITE-SERBIAN	1	0.01	
WHITE-TURKISH CYPRIOT	13	0.13	
WHITE-TRAVELLER	1	0.01	
WHITE-TURKISH	19	0.19	
WHITE-WELSH	5	0.05	
Total	10000	100	

3.10 The Final Sample

Having recorded any ethnic details in the Initial List, the DPT was checked to verify that it met the required criteria which were as follows:

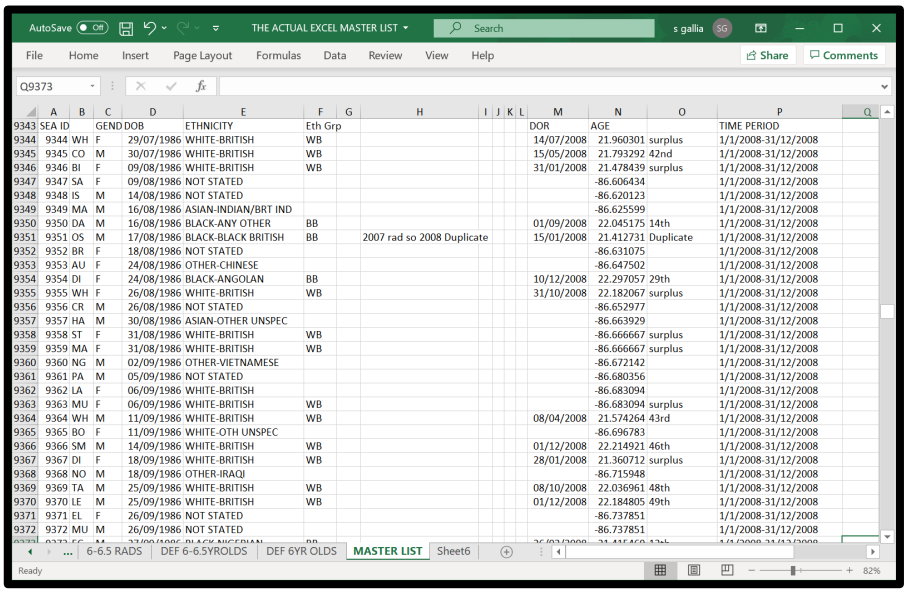
Subject inclusion criteria

1. The existence of a DPT on the GSTT Romexis® database taken when aged between 6.00 and 23.99 years of age.
2. A self-assigned ethnic group being White-British or Black-British or any other Black ethnicity.

Subject exclusion criteria

1. DPT does not show at least one side of the dentition in the third molar region.
2. Date of DPT is unclear, e.g., a copy entered on the Romexis® database at a later date.
3. DPT is of such poor quality that tooth development stages are generally unclear.
4. Uncertainty of tooth identification, e.g., whether a tooth is a first, second, or third molar, or generalised unusual tooth morphology or pathology precluding assessment.
5. Duplicated subjects: subjects were represented by one DPT so that once one DPT for a subject became part of the sample, any other DPTs for that subject were excluded from the study.

If all criteria were met, this DPT became part of the sample and was marked as such in a further column of the Initial List. Checking for duplication involved looking at the data already collected in the Access database in conjunction with the Initial List in Excel and if a DPT of the same subject was already present, this DPT was marked as a duplicate in the Initial List so as not to be included in the sample. The Initial List was also used to prevent more than 50 subjects' data being collected in each half-yearly group. This was done using a column to calculate the age of the subject using the formula (DOR-DOB)/365.25 and marking any subjects over the quota as surplus and not for inclusion in the sample (Figure 14).



	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
9343	SEA ID		GEND	DOB	ETHNICITY	Eth Grp							DOR	AGE		TIME PERIOD	
9344	9344	WH	F	29/07/1986	WHITE-BRITISH	WB							14/07/2008	21.960301	surplus	1/1/2008-31/12/2008	
9345	9345	CO	M	30/07/1986	WHITE-BRITISH	WB							15/05/2008	21.793292	42nd	1/1/2008-31/12/2008	
9346	9346	BI	F	09/08/1986	WHITE-BRITISH	WB							31/01/2008	21.478439	surplus	1/1/2008-31/12/2008	
9347	9347	SA	F	09/08/1986	NOT STATED									-86.606434		1/1/2008-31/12/2008	
9348	9348	IS	M	14/08/1986	NOT STATED									-86.620123		1/1/2008-31/12/2008	
9349	9349	MA	M	16/08/1986	ASIAN-INDIAN/BRT IND									-86.625599		1/1/2008-31/12/2008	
9350	9350	DA	M	16/08/1986	BLACK-ANY OTHER	BB							01/09/2008	22.045175	14th	1/1/2008-31/12/2008	
9351	9351	OS	M	17/08/1986	BLACK-BLACK BRITISH	BB		2007 rad so 2008 Duplicate					15/01/2008	21.412731	Duplicate	1/1/2008-31/12/2008	
9352	9352	BR	F	18/08/1986	NOT STATED									-86.631075		1/1/2008-31/12/2008	
9353	9353	AU	F	24/08/1986	OTHER-CHINESE									-86.647502		1/1/2008-31/12/2008	
9354	9354	DI	F	24/08/1986	BLACK-ANGOLAN	BB							10/12/2008	22.297057	29th	1/1/2008-31/12/2008	
9355	9355	WH	F	26/08/1986	WHITE-BRITISH	WB							31/10/2008	22.182067	surplus	1/1/2008-31/12/2008	
9356	9356	CR	M	26/08/1986	NOT STATED									-86.652977		1/1/2008-31/12/2008	
9357	9357	HA	M	30/08/1986	ASIAN-OTHER UNSPEC									-86.663929		1/1/2008-31/12/2008	
9358	9358	ST	F	31/08/1986	WHITE-BRITISH	WB								-86.666667	surplus	1/1/2008-31/12/2008	
9359	9359	MA	F	31/08/1986	WHITE-BRITISH	WB								-86.666667	surplus	1/1/2008-31/12/2008	
9360	9360	NG	M	02/09/1986	OTHER-VIETNAMESE									-86.672142		1/1/2008-31/12/2008	
9361	9361	PA	M	05/09/1986	NOT STATED									-86.680356		1/1/2008-31/12/2008	
9362	9362	LA	F	06/09/1986	WHITE-BRITISH									-86.683094		1/1/2008-31/12/2008	
9363	9363	MU	F	06/09/1986	WHITE-BRITISH	WB								-86.683094	surplus	1/1/2008-31/12/2008	
9364	9364	WH	M	11/09/1986	WHITE-BRITISH	WB							08/04/2008	21.574264	43rd	1/1/2008-31/12/2008	
9365	9365	BO	F	11/09/1986	WHITE-OTH UNSPEC									-86.696783		1/1/2008-31/12/2008	
9366	9366	SM	M	14/09/1986	WHITE-BRITISH	WB							01/12/2008	22.214921	46th	1/1/2008-31/12/2008	
9367	9367	DI	F	18/09/1986	WHITE-BRITISH	WB							28/01/2008	21.360712	surplus	1/1/2008-31/12/2008	
9368	9368	NO	M	18/09/1986	OTHER-IRAQI									-86.715948		1/1/2008-31/12/2008	
9369	9369	TA	M	25/09/1986	WHITE-BRITISH	WB							08/10/2008	22.036961	48th	1/1/2008-31/12/2008	
9370	9370	LE	M	25/09/1986	WHITE-BRITISH	WB							01/12/2008	22.184805	49th	1/1/2008-31/12/2008	
9371	9371	EL	F	26/09/1986	NOT STATED									-86.737851		1/1/2008-31/12/2008	
9372	9372	MU	M	26/09/1986	NOT STATED									-86.737851		1/1/2008-31/12/2008	

Figure 14. Example from Initial List in Excel

Table 3 shows the distribution of self-assigned ethnicities in the Black British and White British groups in the final sample. Other reasons for so many more subjects in the Initial List, apart from multiple DPTs per subject, are illustrated by the five White-Welsh subjects in the Initial List who were either over the 24 year age limit (1) or their age group was already complete (4), leaving only one subject self-identifying as White-Welsh included in the final sample.

The ethnic categories on the registration form do not include country-specific options. Therefore, patients who chose to self-identify as White-English, Scottish, or Welsh would be considered White-British if the GSTT categorisation is adhered to. Similarly, if those who stated Black ethnicity together with a specific African country are grouped in the GSTT category of Black-Other African, this narrows the Black ethnicities to the main GSTT categories. Figure 15 illustrates the distribution of these self-assigned Black ethnicities in the final sample (2,035 subjects).

Table 3. Self-Assigned Ethnicities in Final Sample

Self-Assigned Ethnicity	Males	Females	Total	Group Total
BLACK-ALGERIAN	1	0	1	
BLACK-ANGOLAN	0	1	1	
BLACK-ANY OTHER	157	167	324	
BLACK-BLACK BRITISH	137	191	328	
BLACK-CARIBBEAN	167	207	374	
BLACK-ERITREAN	3	6	9	
BLACK-ETHIOPIAN	2	5	7	Black British
BLACK-GHANAIAN	4	7	11	Group
BLACK-MIXED BLACK	4	8	12	2,036
BLACK-NIGERIAN	36	47	83	
BLACK-OTHER AFRICAN	390	399	789	
BLACK-OTHER UNSPEC	10	11	21	
BLACK-SOMALI	37	30	67	
BLACK-SUDANESE	1	2	3	
BLACK-UGANDAN	4	2	6	
WHITE-BRITISH	1,662	1,720	3,382	
WHITE-ENGLISH	111	58	169	White British
WHITE-SCOTTISH	2	0	2	Group
WHITE-WELSH	0	1	1	3,554
Total	**2,728**	**2,862**	**5,590**	**5,590**

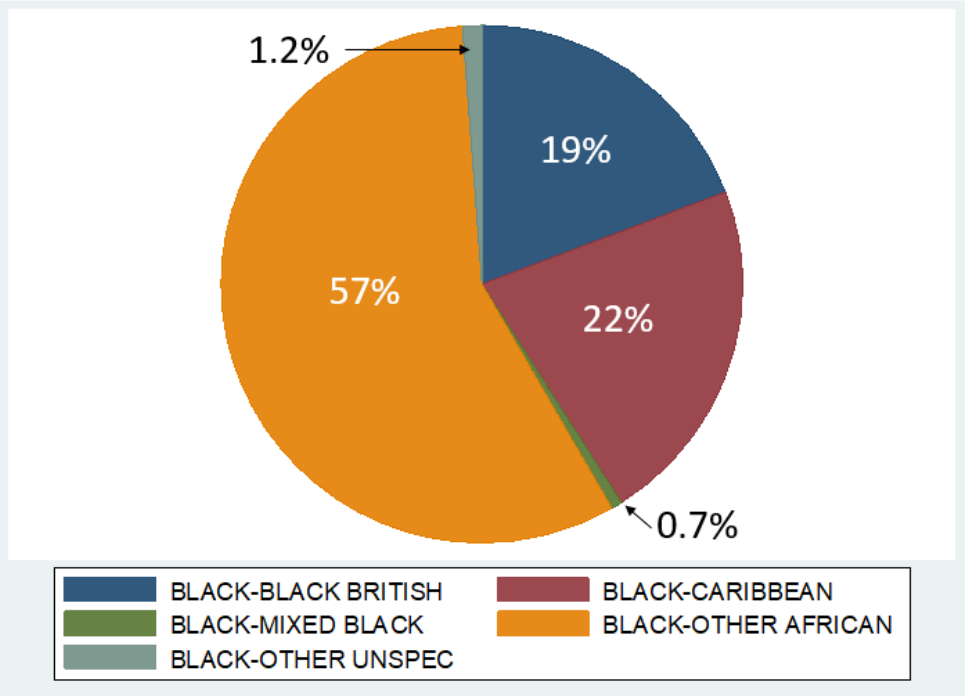


Figure 15. Chart to show proportions of Black ethnicities in final sample

The final sample (Table 4) totalled 5,590 subjects of whom 2,035 were in the Black British group and 3,555 in the White British group. There were 50 male and 50 female White British subjects in each half-yearly group between the ages of 7.00 and 23.99 years; and at least 25 male and 25 female Black British subjects between the ages of 9.00 and 23.99 years (Figure 16 and Table 5). The red horizontal lines in Figure 16 indicates the 25 per group threshold.

Table 4. Ethnicity and sex distribution of sample

	Male	Female	**Total**
White British	1,775	1,780	**3,555**
Black British	953	1,082	**2,035**
Total	**2,728**	**2,862**	**5,590**

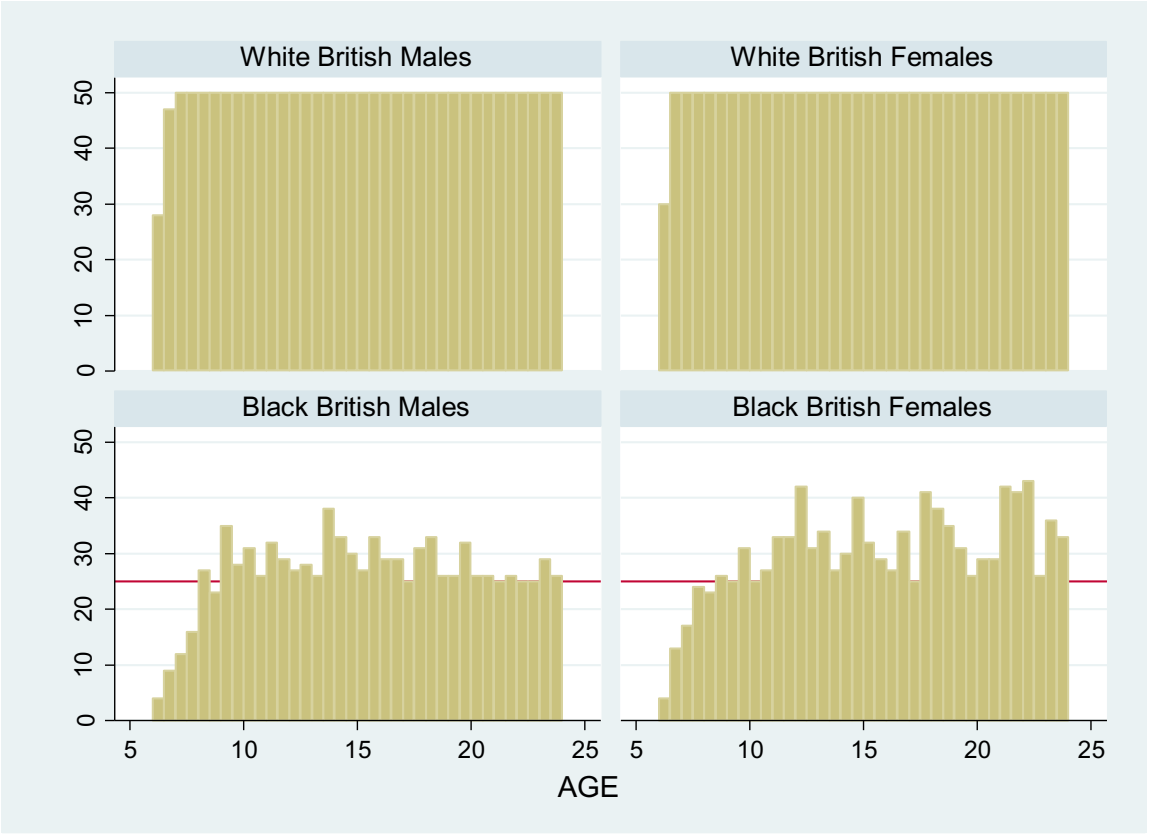


Figure 16. Histograms showing age distribution of sample

Table 5. Table showing age distribution of sample

Age (Years)	WB Males	WB Females	Total WB	BB Males	BB Females	Total BB	Total Males	Total Females	Total
6-6.5	28	30	58	4	4	8	32	34	66
6.5-7	47	50	97	9	13	22	56	63	119
7-7.5	50	50	100	12	17	29	62	67	129
7.5-8	50	50	100	16	24	40	66	74	140
8-8.5	50	50	100	27	23	50	77	73	150
8.5-9	50	50	100	23	26	49	73	76	149
9-9.5	50	50	100	35	25	60	85	75	160
9.5-10	50	50	100	28	31	59	78	81	159
10-10.5	50	50	100	31	25	56	81	75	156
10.5-11	50	50	100	26	27	53	76	77	153
11-11.5	50	50	100	32	33	65	82	83	165
11.5-12	50	50	100	29	33	62	79	83	162
12-12.5	50	50	100	27	42	69	77	92	169
12.5-13	50	50	100	28	31	59	78	81	159
13-13.5	50	50	100	26	34	60	76	84	160
13.5-14	50	50	100	38	27	65	88	77	165
14-14.5	50	50	100	33	30	63	83	80	163
14.5-15	50	50	100	30	40	70	80	90	170
15-15.5	50	50	100	27	32	59	77	82	159
15.5.16	50	50	100	33	29	62	83	79	162
16-16.5	50	50	100	29	27	56	79	77	156
16.5-17	50	50	100	29	34	63	79	84	163
17-17.5	50	50	100	25	25	50	75	75	150
17.5-18	50	50	100	31	41	72	81	91	172
18-18.5	50	50	100	33	38	71	83	88	171
18.5-19	50	50	100	26	35	61	76	85	161
19-19.5	50	50	100	26	31	57	76	81	157
19.5-20	50	50	100	32	26	58	82	76	158
20-20.5	50	50	100	26	29	55	76	79	155
20.5-21	50	50	100	26	29	55	76	79	155
21-21.5	50	50	100	25	42	67	75	92	167
21.5-22	50	50	100	26	41	67	76	91	167
22-22.5	50	50	100	25	43	68	75	93	168
22.5-23	50	50	100	25	26	51	75	76	151
23-23.5	50	50	100	29	36	65	79	86	165
23.5-24	50	50	100	26	33	59	76	83	159
Grand Totals	**1775**	**1780**	**3555**	**953**	**1082**	**2035**	**2728**	**2862**	**5590**

3.11 Data Collection

Step 1. Use of the Initial List to enter subjects in an Access database

Once the Initial list was established in Excel and in preparation for TDS data collection in Access, the Initial List was printed out in two versions: the first only showing the ID, first two letters of the surname and DOR, and the second including details of DOB and self-assigned ethnicity. The Study ID's of subjects on the list who met all the criteria required for the sample, were highlighted on the first printed list and the second list put aside so that ethnicity and DOB were blinded from the observer. Data collection depended on having the first printed list to hand, a GSTT computer open and running Romexis®, and a separate computer open and running the Access database.

Dental data from DPTs was collected in a way designed to blind the observer from personal details and minimise bias. The first step of adding subjects' data to the Access database was the addition of a Study ID number and DOR to the "Personal Details" Access form (Figure 17), one form for each subject, adding a separate record for each the highlighted subjects shown on the printed-out Initial List. The database also automatically generates a DARLInG ID each time a record is added. The Study ID and DARLInG ID ensure referential integrity without recourse to any identifiable information with, according to convention in all DARLInG Access databases, the DARLInG ID as the "primary key".

This preparatory step was carried out before the required DPTs were viewed and was generally done in groups of 50 subjects.

The next step was to add dental data from the DPTs to the Access database without knowledge of subjects' personal details.

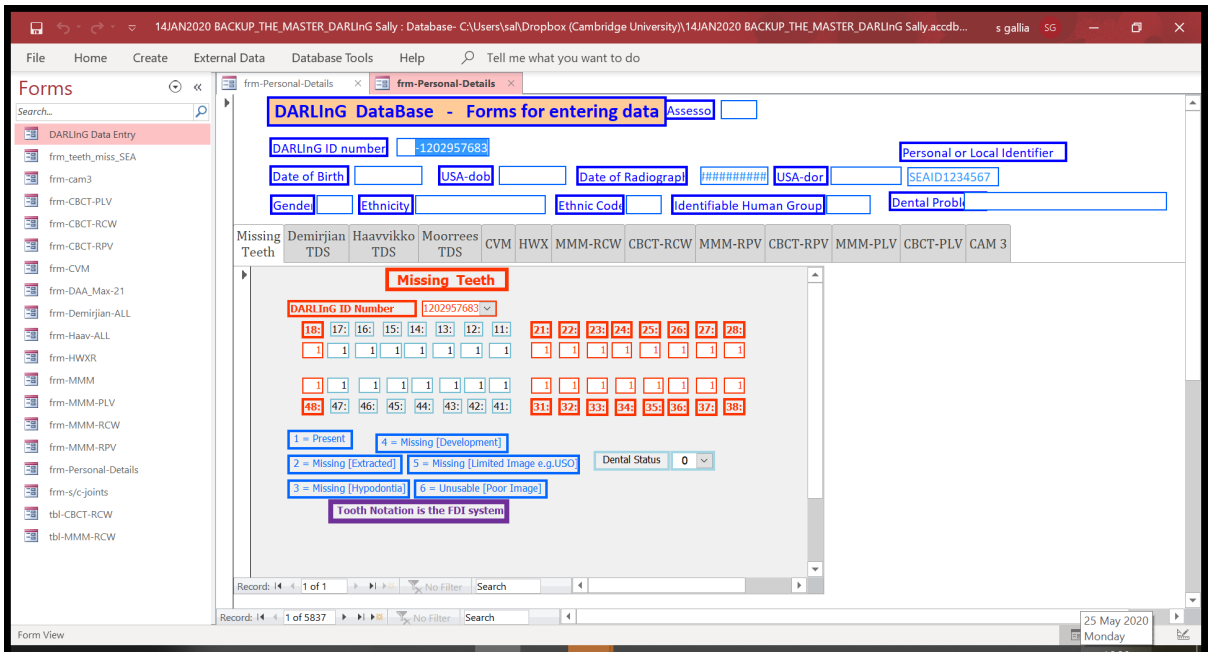


Figure 17. Access Personal Details Form with ID numbers and DOR added (obscured) but other personal details not yet added, and Missing Teeth Form showing all teeth present but Dental Status field not yet completed. (Permission for reproduction granted by Professor Graham Roberts / DARLInG)

Step 2. Adding dental data to the Access database

Romexis® was then opened on the GSTT computer. Parts of the computer screen were shielded from view using a system of paper screens. Once the required list of DPTs in DOB order was brought up on the screen for the time period required, and thus arranged as for compilation of the Initial List, the list on the GSTT computer screen was hidden from view apart from the first two letters of the surnames. The DPT required, shown highlighted on the printed list, was recognised by looking at and matching the order of the first two letters of the surnames. Selecting the individual DPT brings up the next Romexis® screen which shows a list of the dental radiographs for the subject. The DPT required is then selected with a check that its DOR agrees with the DOR on the printed list.

Concurrently, the Access database was open on a separate computer and showing the Personal Details Form of the relevant subject containing, so far, only ID numbers and DOR, the DOR being automatically obscured from view (Figure 17). The DPT is examined and the

TDS and dental data entered on all the relevant Access forms with the observer unaware of name, DOB, DOR, age, sex or ethnicity.

All images were viewed directly on a calibrated computer monitor. The images were enlarged up to 100% and the contrast, brightness, and sharpness improved using the computer software as appropriate for each DPT.

With a possible timespan in the GSTT Romexis® database from 2005 until the present day, data collection ended in January 2020 with DPTs in the final sample spanning the period 30/03/2005 to 16/12/2019.

Teeth Present or Missing

The detection of developing teeth or agenesis was generally straightforward but other radiographs, not necessarily DPT's, were checked to clarify from the radiographic history less obvious features of the dentition such as, for example, whether missing premolars had been removed for orthodontic reasons or were developmentally missing.

The presence or absence of each permanent tooth was recorded using the DARLInG system on the "Missing Teeth" Access Form with the addition of fields for the teeth on the right side added for the purposes of this study. For developmentally missing teeth, this system has separate code for developmentally missing third molars compared to all other permanent teeth which are allocated a code for hypodontia. The following codes are used: 1- Present; 2 - Missing (extracted); 3- Missing (hypodontia); 4 - Missing (developmentally missing third molar); 5 - Tooth in area not shown on radiograph; 6 - Poor image (tooth seen to be present but TDS allocation not possible). A tooth was recorded as developmentally absent (Categories 3 and 4) if there was no indication of the presence of a radiolucent crypt nor any evidence of the tooth.

A system for classifying the status of the dentition as a whole, termed Dentition Status, was devised for this study, and a new field added in the DARLInG Missing Teeth Access Form, with categories as follows: 1 - Complete permanent dentition; 2 - All permanent teeth present except one or more third molars; 3 - Hypodontia (1-5 permanent teeth

developmentally missing) AND one or more missing third molars; 4 - Oligodontia (more than five permanent teeth developmentally missing) AND one or more missing third molars; 5 - Hypodontia only (1-5 permanent teeth developmentally missing) with no missing third molars; 6 - Oligodontia only (more than five permanent teeth developmentally missing) with no missing third molars; 7 - Unsure (e.g. if dentition appears so young that teeth may still develop); 8 – Other (Conditions identifiable from the DPT, e.g. cleft palate, which may affect dental development).

TDS

According to standard practice in DAE studies, TDS data using the Demirjian eight stage system, Stages A, B, C, D, E, F, G and H (TDS) [65] of the left-sided permanent teeth and all four third molars. This assessment process utilised schematic diagrams (Figure 18) and written descriptions (Figure 19) of the Demirjian TDSs to assist in the precise assessment of dental developmental stages. Contrary to standard DAE practice, there was no substitution of right-sided teeth when left-sided teeth were missing so that a TDS was only allocated to teeth that were actually present. If, however, the apices of left-sided teeth other than third molars were obscured or blurred, information from the antimere was used to assist TDS assessment of the left-sided tooth. Third molar TDS were all assessed independently.

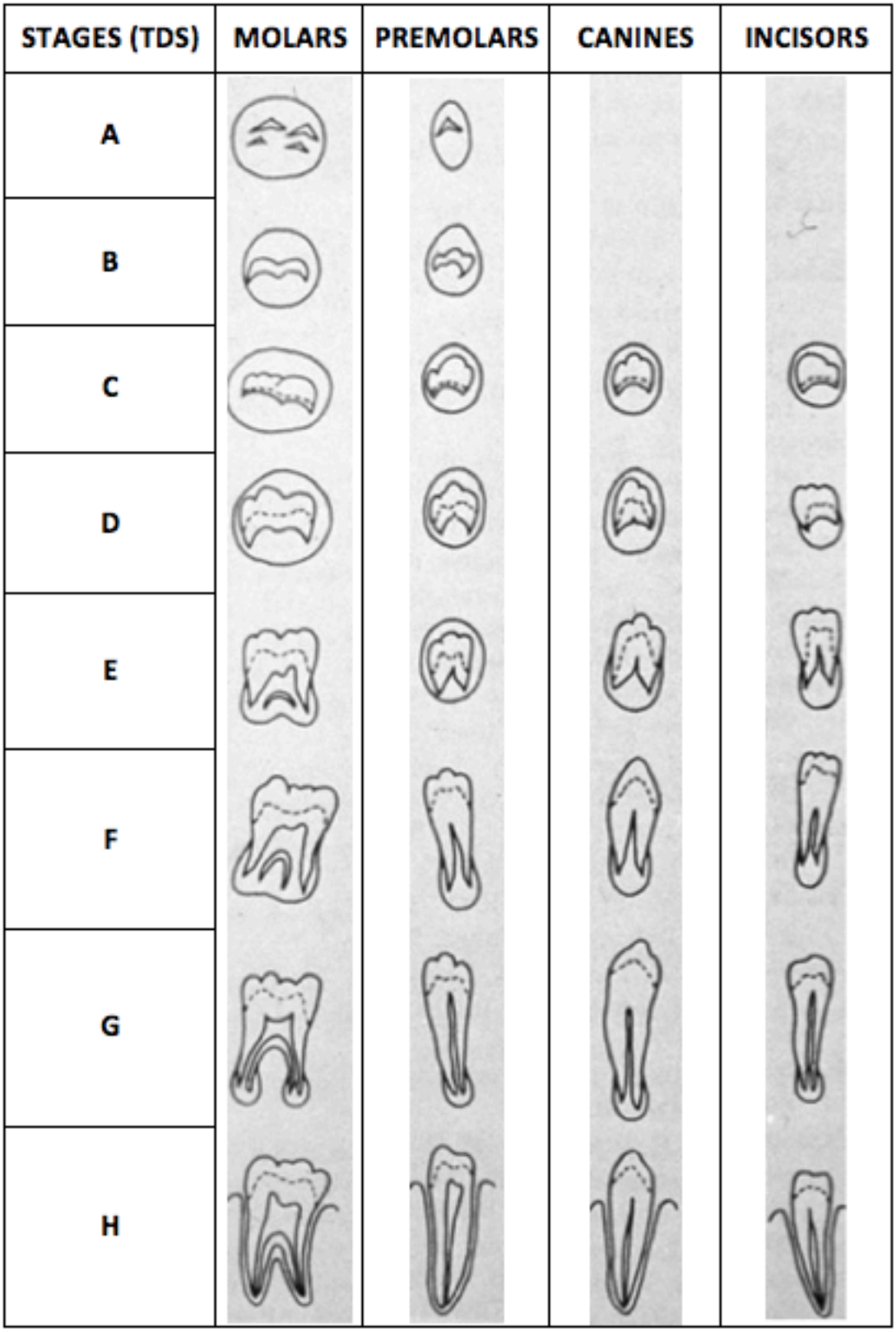


Figure 18. Pictorial representations for Demirjian's system of rating developmental stages for permanent teeth [288]. (Permission for reproduction granted by Wayne State University.)

STAGES (TDS)	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 chamber 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 length is still less than the crown height. 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 height. MULTIRADICULAR TEETH a. The calcified region of the bifurcation has developed further down from its semilunar stage to give the roots a more definitive 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 of molars) b. The periodontal membrane has a uniform width around the root and apex

Figure 19. Written descriptions for Demirjian's system of rating developmental stages for permanent teeth [65]. (Permission for reproduction granted by Wayne State University.)

Radiographic examples of the eight stages in the lower left third molar taken from the research sample are shown in Figure 20.

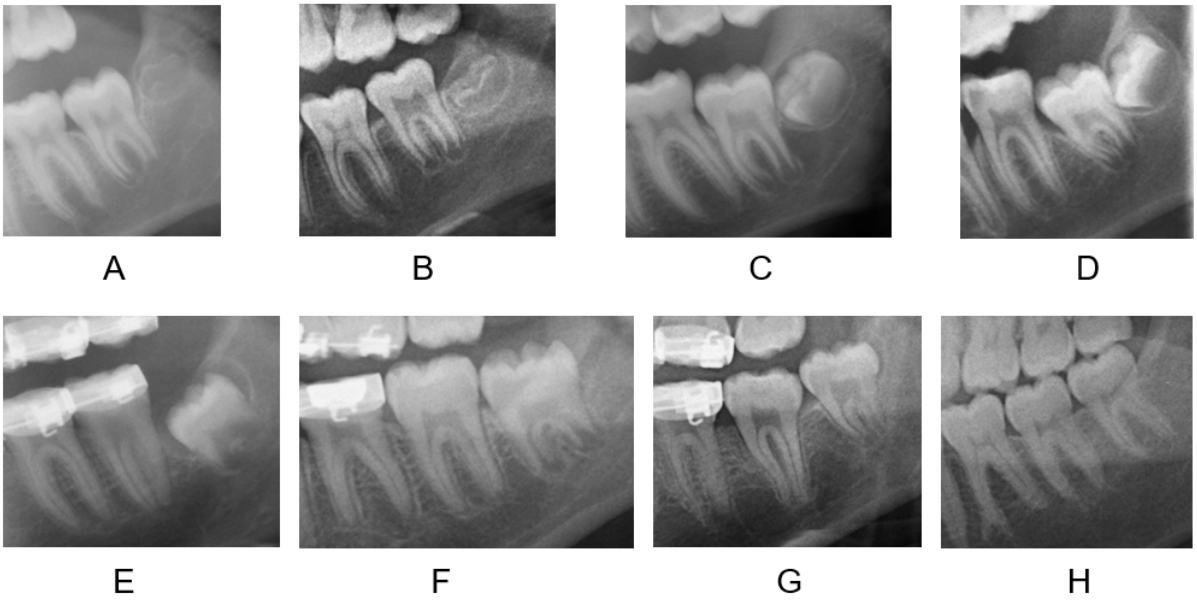


Figure 20. Examples of the eight Demirjian Stages in the LL8.

After dental data collection of, for example, a group of 50 subjects, the DOB, sex and ethnic group were added to the Personal Details Form by consulting the second version of the printed Excel list which contained these details. For ease, and also to ensure that no dental data could be seen at this stage, personal data was added to the Personal Details Table (Figure 21) rather than the related Personal Details Form which did contain, by this time, some dental data. The completed Personal Details, Missing Teeth and Demirjian TDS Access Forms, the latter two on separate tabs, are shown in Figures 22 and 23.

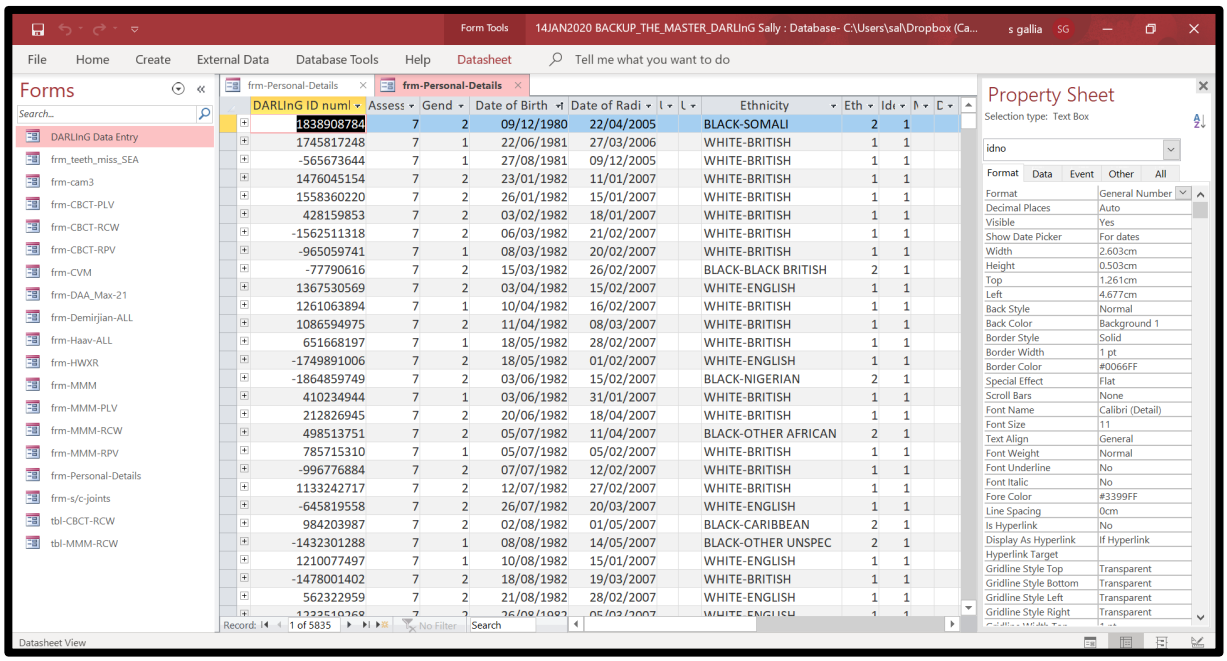


Figure 21. Completed Personal Details Table in Datasheet View. (Permission for reproduction granted by Professor Graham Roberts / DARLInG)

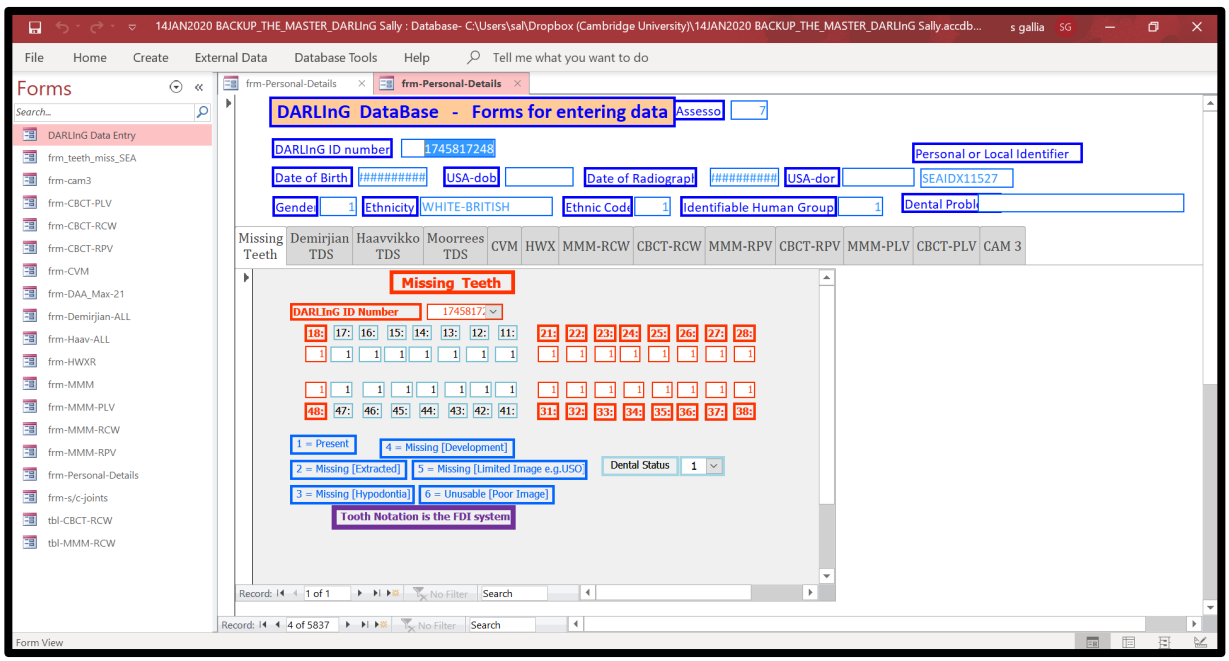


Figure 22. Completed Personal Details and Teeth Present Forms. N.B. Forms already present in the Access design but not used in this study, such as for Haavikko TDS and Moorees TDS data collection, were left in situ as recommended. (Permission for reproduction granted by Professor Graham Roberts / DARLInG)

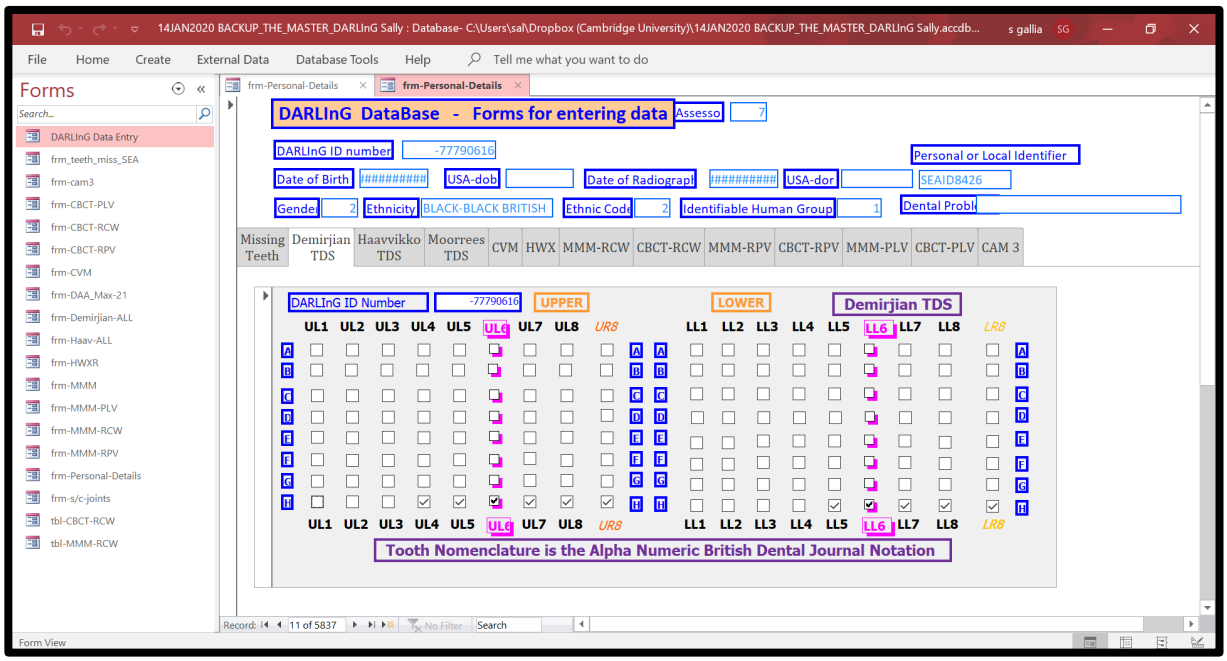


Figure 23. Completed Personal Details and Demirjian TDS Forms. (Permission for reproduction granted by Professor Graham Roberts / DARLInG)

Once all the required data had been collected, it was imported into Excel worksheets using Access Queries and, in turn, imported into Stata® for data analysis. Statistical analyses were supervised by GSTT Statistician, Mrs Fiona Warburton.

3.12 Avoidance of observer bias

This method of using the printed-out Initial List with limited personal information, together with a system of paper sheets attached to the computer monitor to shield parts of the screen from view, and the above order of data collection on Access, allowed DPT's to be found, viewed, and dental data collected without the observer's knowledge of a subject's name, sex, ethnic code and age. This was found to be the most effective way to reduce observer bias. With one-year time intervals on the Romexis® system, the possible age of a subject has a two year range, although that age range is not known to the observer because the actual age is further obfuscated by the age range changing as the list progresses. DOBs were at first available to the observer when a new section of Romexis® needed to be viewed, e.g. another year of DPTs, but at all stages of data collection, as well as hiding the DOB from view

whenever possible, there was a purposeful avoidance of any calculation of age or of any other personal detail for which sight could not be avoided and, while understanding the risk of unconscious bias, a conscious effort was made to avoid bias. Also, from the start and at many stages of data collection, groups of ten DPTs were viewed in random order in a further effort to minimise bias. In any case, calculating age would have been very time-consuming and the instinct was to collect the TDS data without the delay of unnecessary distraction. It was not possible to know the name, sex or ethnic group of the subject using this system.

As there are many more White British than Black British subjects in the Romexis® database, data collection for White British moved ahead more quickly. Once the full complement of data for White British individuals had been collected, data from the very last few Black British subjects only was being collected. This inevitably could lead to bias but all other personal details, as explained above, remained unknown to the observer.

3.13 Intra-rater and Inter-rater Agreement

Intra-rater agreement for TDS was tested at stages throughout data collection. About halfway through data collection, inter-rater agreement was tested with Dr Maxi Malekniazi, a forensic odontologist experienced in viewing DPTs and Demirjian TDS, with a sample of 50 DPTs representing a wide age range. One final test was arranged for intra-rater agreement which was carried out using 98 DPTs chosen and anonymised by a third party and only the four third molars were assessed. The DPTs were viewed as images in a Microsoft® Word file rather than in Romexis® while working from home under the COVID-19 arrangements. The Kappa scores were independently calculated by Statistician Mrs Fiona Warburton, using the weighted Kappa calculation, as opposed to the non-weighted Kappa calculation which was used for all the other tests.

The results of intra- and inter-rater agreement are given in Tables 6. The Kappa scores for the intra-rater tests all indicate high levels of agreement, Stata suggesting the following levels of agreement:

Below 0.0 Poor
0.00 - 0.20 Slight
0.21 - 0.40 Fair
0.41 - 0.60 Moderate
0.61 - 0.80 Substantial
0.81 - 1.00 Almost perfect

Lower levels of intra-rater agreement were seen in the final test using 98 DPTs for assessment of the third molars alone, and each independently. These scores could be partly explained by the inevitable loss of detail and clarity which could have led to more third molars being rated as unassessable in this sample of copied images. It should also be noted that weighted Kappa scores may be expected to be lower than non-weighted Kappa scores. Overall, observer reproducibility was excellent.

Table 6. Intra-rater and inter-rater reproducibility test results.

Date	**Type**	**Cohen's Kappa Score / Agreement rating***	**Comments**
April and June 2018	Intra-rater	Left-sided teeth and all third molars 0.9452 Almost perfect	10 DPT's Assessed two months apart
August 2019	Intra-rater	Left-sided teeth and all third molars 0.9031 Almost perfect	6 DPT's Compared with data from duplicates found in sample with first assessment in early 2018.
September 2019	Intra-rater	Left-sided teeth and all third molars 0.9069 Almost perfect	20 DPT's 1st Assessment early in study
May 2019	Inter-rater	Left-sided teeth and all third molars 0.9365 Almost perfect	50 DPT's Range of age & ethnic groups. 2nd assessor (trained, experienced TDS assessor)
July 2020	Intra-rater NB Weighted Kappa calculations Romexis images compared with images copied into a Microsoft® Word document.	UR8: 0.8621 Almost perfect	98 DPTs Third molars only assessed. Results for single third molars. 1st Assessment early in study, 2nd assessment July 2020
		UL8: 0.8189 Almost perfect	
		LL8: 0.7256 Substantial	
		LR8: 0.7011 Substantial	

Chapter 4

Results

4.1 The timing of third molar development

DAE at the 18-year-old threshold is based on the timing of development of the third molar. The first null hypothesis was that the age associated with defined third molar development stages in UK subjects is the same in Black British and White British ethnic groups. To address this, an analysis of age at assessment of third molar Demirjian TDSs in males of females of both ethnic groups is presented.

The summary data for each TDS of third molars for males and females are shown in Tables 7 and 8 which consistently show an ethnic difference for every TDS with the mean age for each TDS occurring earlier in the Black British group compared to the White British group. Student's t test, with the Bonferroni correction to adjust for multiple testing giving a p value of 0.0016 to denote statistical significance, shows that these differences are all highly significant for all stages B-G in males and females, except for UL8 Stages E ($p=0.0091$) and F ($p=0.0001$) in males, and UR8 Stages D ($p=0.0002$) and G ($p=0.0001$) in females. Similarly significant ethnic differences for upper third molars at Stage A are not demonstrated in females ($p<0.01$) or males but may be explained by the smaller numbers, especially of male subjects, with upper third molars at Stage A.

Data for Stage H cannot be interpreted in the same way as other TDS because once Stage H is established it persists throughout life and results do not follow a normal distribution. Stage H data is therefore non-parametric so Mann-Whitney tests were applied after censoring the maximum age for Stage H at the maximum age seen for Stage G using a method described by Roberts et al [289, 290]. According to this method, any subjects with Stage G whose age is more than three times the SD from the mean for Stage G are discarded before the maximum age for Stage G is determined. An example of this is the one subject in the sample, a White British

male aged 23.41 years with LL8 at Stage G, whose age at this stage was 3SD outside 3SD of the mean and was discarded from the Stage G data. Applying the Mann Whitney Test for the non-parametric data of Stage H, highly significant differences are seen in both males and females for all four third molars.

For all third molars, every TDS was found at a younger age in the Black British group compared to the White British group. The ethnic difference was greater in females than it was in males. It was also more pronounced regarding lower third molars compared to upper third molars. The average mean age difference for Stages A-H being, for lower third molars in males, 1.49 years, and in females, 1.68 years. For upper third molars, the average difference was 1.11 years in males and 1.20 yrs in females. In both males and females, Stages B and C in all third molars show consistently the greatest difference in developmental timing with this difference being 1.9 years for lower third molars in females.

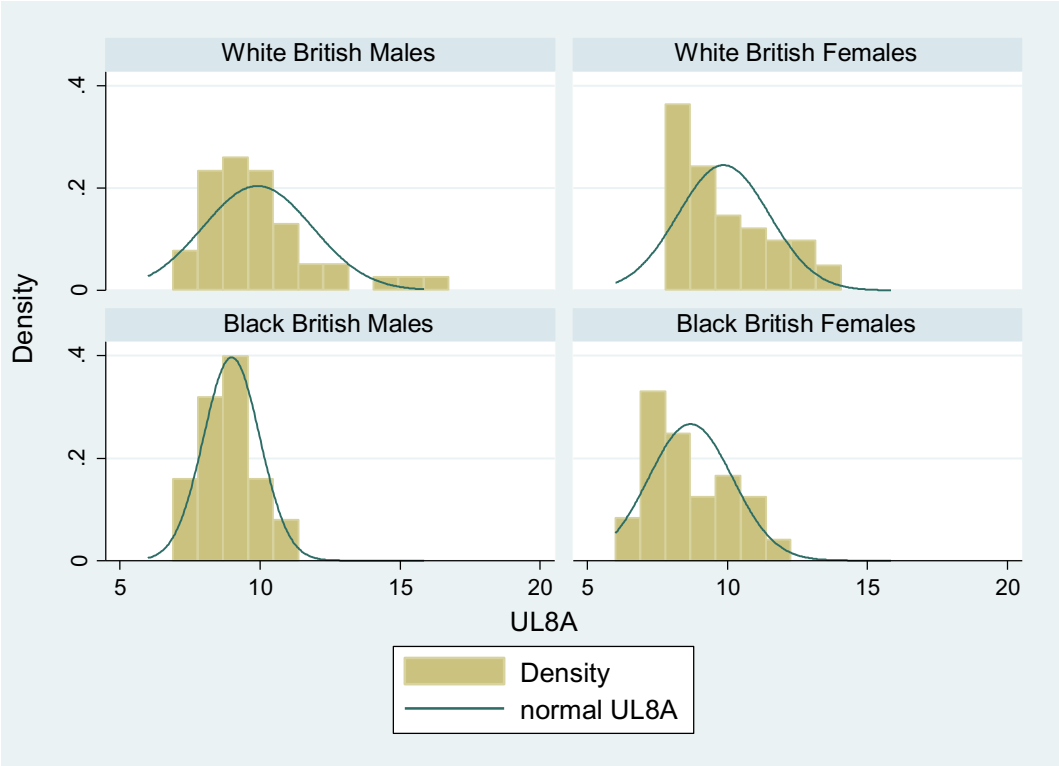
Table 7. Results for Third Molars Stages A-H for Males. T tests applied to TDS A-G and Mann Whitney tests to censored data at TDS H.

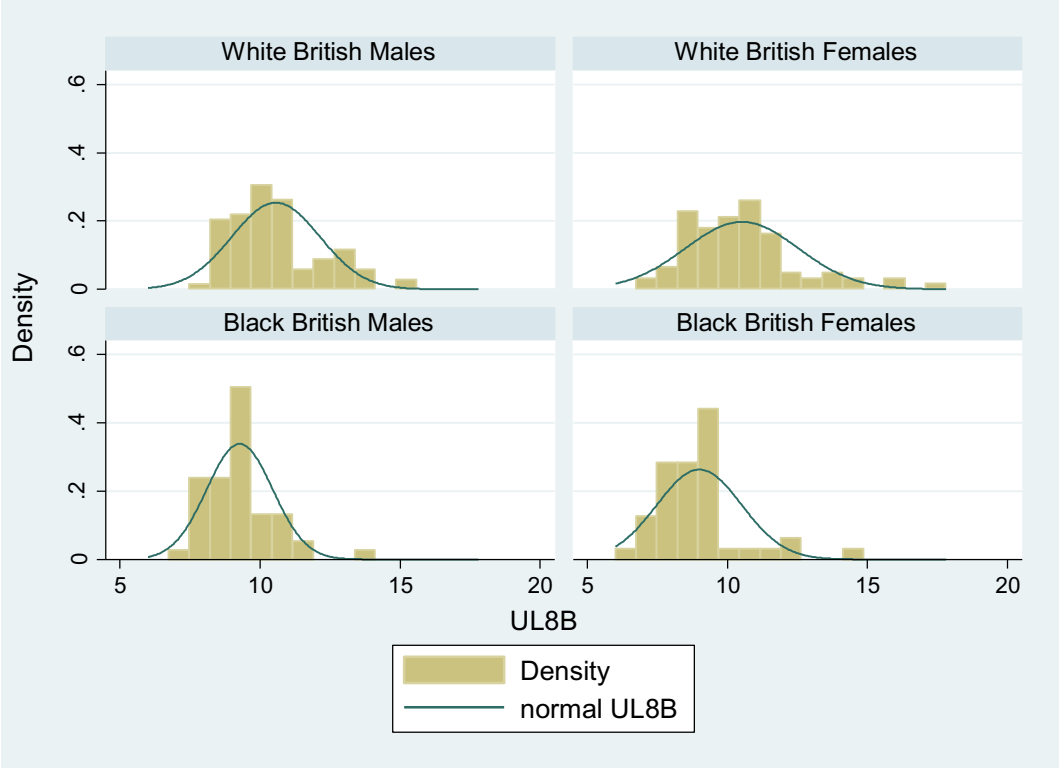
	Results for third molars Stages A-H for Males											
	Black British					difference between Means	p value	White British				
TDS	n	Mean (Median)	SD	Min	Max			n	Mean (Median)	SD	Min	Max
UR8A	16	8.97	1.34	6.97	12.35	0.44	0.3593	33	9.41	1.63	6.80	15.31
UR8B	51	9.21	0.96	7.39	11.63	1.54	<0.0001	114	10.75	1.78	7.69	15.85
UR8C	97	10.65	1.55	7.69	14.64	1.58	<0.0001	157	12.23	1.82	8.48	17.39
UR8D	124	12.65	1.52	8.25	16.36	1.05	<0.0001	133	13.70	1.71	7.81	21.74
UR8E	84	14.01	1.59	10.07	20.04	1.19	<0.0001	106	15.21	1.85	10.77	19.66
UR8F	75	15.91	1.37	13.09	19.53	1.01	<0.0001	92	16.92	1.63	13.15	21.57
UR8G	74	17.07	1.58	12.89	21.27	1.09	<0.0001	90	18.16	1.44	14.88	21.90
UR8H	133	19.19 (19.31)		15.75	21.25	0.70	<0.0001	216	19.89 (20.17)		9.58	21.89
UL8A	14	8.99	1.00	7.55	10.63	0.92	0.0962	43	9.91	1.95	7.41	15.85
UL8B	51	9.28	1.18	7.39	13.68	1.29	<0.0001	93	10.57	1.57	8.17	15.40
UL8C	100	10.64	1.48	8.18	15.68	1.65	<0.0001	162	12.29	1.98	6.85	18.35
UL8D	122	12.69	1.56	8.25	17.16	1.17	<0.0001	138	13.85	1.85	7.81	18.60
UL8E	90	14.23	1.61	11.24	19.83	0.66	0.0091	106	14.88	1.84	10.77	20.49
UL8F	71	15.88	1.42	13.09	20.04	0.99	0.0001	101	16.87	1.63	13.15	21.57
UL8G	69	17.05	1.57	12.92	20.47	1.05	<0.0001	94	18.11	1.52	14.46	21.90
UL8H	126	18.61 (18.79)		12.89	20.45	1.35	<0.0001	233	19.96 (20.16)		9.58	21.89
LL8A	33	8.49	1.01	6.21	10.46	1.41	<0.0001	107	9.90	1.75	6.80	15.09
LL8B	66	9.46	1.24	7.58	13.62	1.94	<0.0001	125	11.40	1.81	7.52	16.70
LL8C	128	11.21	1.63	8.36	15.69	1.62	<0.0001	184	12.83	1.79	8.48	17.87
LL8D	82	12.86	1.48	8.25	16.36	1.38	<0.0001	67	14.23	1.74	10.29	19.28
LL8E	100	14.44	1.55	11.37	19.53	1.33	<0.0001	134	15.77	1.82	10.81	21.57
LL8F	72	16.05	1.29	13.09	19.39	1.37	<0.0001	87	17.42	1.51	13.15	20.83
LL8G	77	17.39	1.52	14.21	22.65	1.41	<0.0001	80	18.80	1.50	15.76	23.41
LL8H	211	19.96 (20.19)		12.89	22.63	0.97	0.0001	288	20.60 (20.80)		16.28	22.84
LR8A	34	8.63	1.25	6.21	11.99	1.41	<0.0001	109	10.04	1.83	6.80	16.68
LR8B	73	9.43	1.19	7.69	13.62	1.92	<0.0001	123	11.35	1.87	7.52	16.70
LR8C	119	11.33	1.53	8.61	15.69	1.47	<0.0001	188	12.80	1.71	8.48	17.68
LR8D	86	12.97	1.65	8.25	16.73	1.42	<0.0001	76	14.39	1.63	10.77	18.39
LR8E	92	14.35	1.39	11.37	18.37	1.61	<0.0001	105	15.96	1.93	10.81	21.57
LR8F	72	16.07	1.31	13.09	19.39	1.24	<0.0001	103	17.31	1.60	13.15	20.83
LR8G	78	17.16	1.58	12.89	21.07	1.57	<0.0001	81	18.74	1.59	15.76	23.41
LR8H	125	19.15 (19.34)		15.75	21.06	1.72	0.0077	307	20.87 (21.07)		16.28	23.40

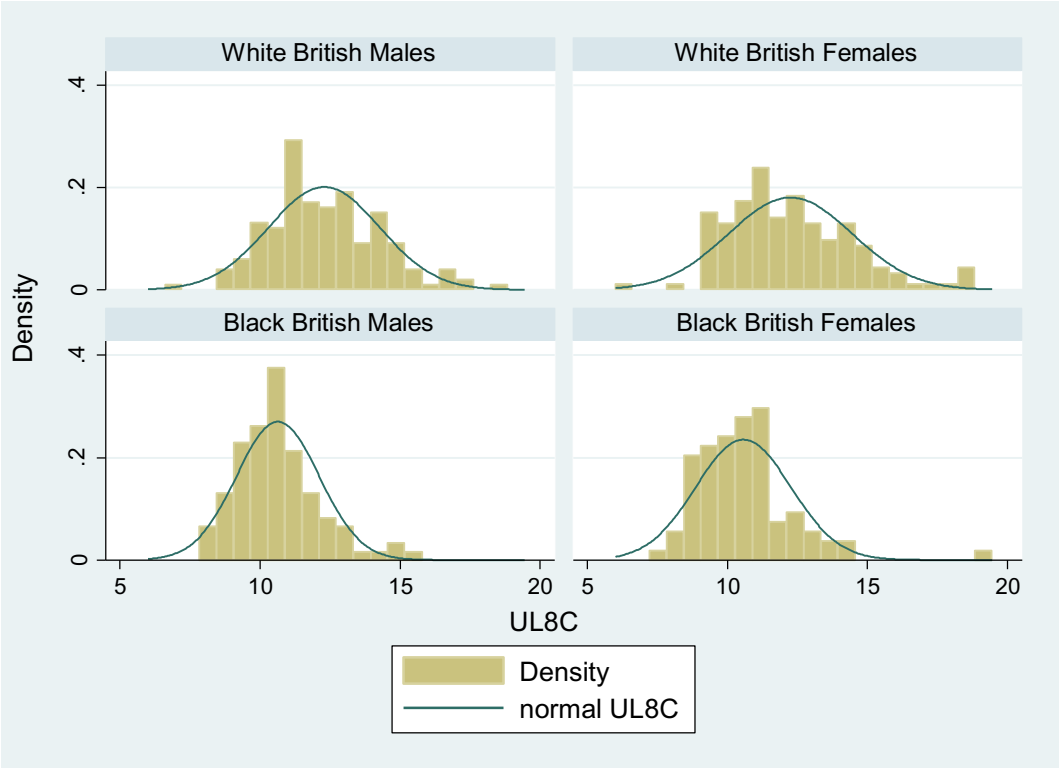
Table 8. Results for Third Molars Stages A-H for Females. T tests applied to TDS A-G and Mann Whitney tests to censored data at TDS H.

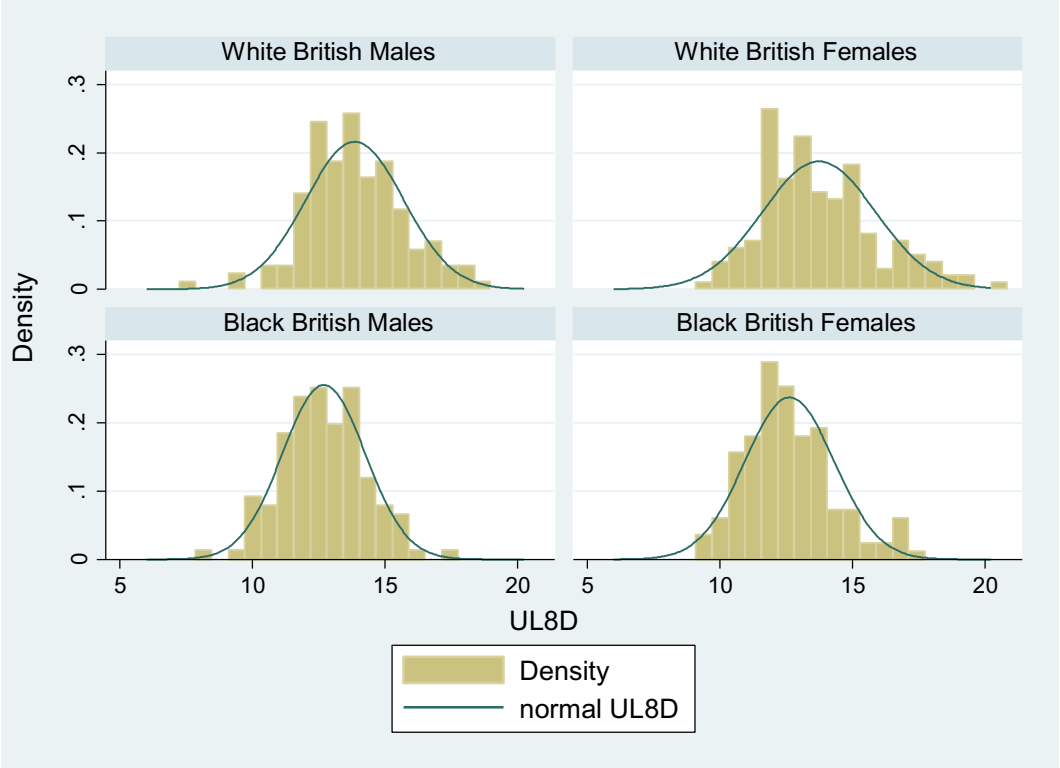
	Results for third molar Stages A-H for Females											
	Black British					difference between Means	p value	White British				
TDS	n	Mean (Median)	SD	Min	Max			n	Mean (Median)	SD	Min	Max
UR8A	23	8.47	1.20	6.84	10.70	1.00	0.0125	49	9.47	1.69	6.86	13.48
UR8B	49	9.10	1.49	6.60	12.22	1.84	<0.0001	80	10.95	2.24	7.23	18.47
UR8C	96	10.61	1.51	7.81	14.94	1.35	<0.0001	152	11.96	1.99	8.18	18.46
UR8D	140	12.86	1.81	9.31	18.74	0.80	0.0002	153	13.67	1.87	9.64	20.23
UR8E	105	14.22	1.82	10.08	18.70	1.26	<0.0001	146	15.48	2.11	11.66	21.21
UR8F	76	15.92	1.75	11.70	19.59	1.15	<0.0001	104	17.07	1.82	13.54	22.35
UR8G	99	17.77	2.43	12.49	23.87	1.29	0.0001	89	19.06	2.04	15.33	23.68
UR8H	258	20.68 (21.10)		13.28	23.83	0.45	0.0002	271	21.13 (21.35)		15.56	23.67
UL8A	27	8.69	1.50	6.69	12.12	1.18	0.0030	46	9.87	1.63	7.84	13.40
UL8B	43	9.00	1.52	6.60	14.31	1.52	<0.0001	83	10.52	2.02	6.86	17.81
UL8C	88	10.57	1.70	7.81	19.45	1.68	<0.0001	151	12.25	2.21	6.36	18.50
UL8D	134	12.63	1.68	9.31	17.54	1.11	<0.0001	159	13.74	2.13	9.64	20.23
UL8E	116	14.38	1.86	10.36	18.74	1.14	<0.0001	155	15.52	2.06	11.69	22.11
UL8F	78	15.88	1.83	11.70	19.59	1.18	<0.0001	99	17.06	1.84	12.96	22.86
UL8G	96	17.70	2.43	12.49	23.66	1.51	<0.0001	111	19.21	2.01	15.33	23.87
UL8H	285	20.64 (21.05)		10.48	23.64	0.75	0.0001	301	21.39 (21.61)		15.56	23.87
LL8A	46	8.14	1.21	6.60	12.59	1.80	<0.0001	115	9.94	1.81	6.86	14.34
LL8B	56	9.20	1.32	6.96	12.24	1.88	<0.0001	110	11.08	1.85	7.61	16.04
LL8C	116	10.97	1.59	7.25	18.40	1.85	<0.0001	180	12.81	1.92	8.56	18.36
LL8D	96	12.96	1.73	10.08	18.74	1.84	<0.0001	120	14.79	2.05	10.43	20.33
LL8E	120	14.26	1.76	10.69	18.71	1.72	<0.0001	136	15.98	1.97	10.98	22.28
LL8F	102	16.18	1.81	11.95	21.49	1.72	<0.0001	95	17.89	2.13	13.97	23.87
LL8G	100	18.04	2.00	13.36	22.96	1.79	<0.0001	114	19.83	1.85	15.81	23.68
LL8H	245	20.34 (20.70)		13.28	22.94	0.96	0.0004	293	21.30 (21.56)		15.56	23.67
LR8A	47	8.42	1.57	6.34	12.59	1.29	<0.0001	96	9.71	1.61	6.86	13.74
LR8B	59	8.99	1.14	6.96	12.19	2.07	<0.0001	119	11.06	1.87	7.61	17.22
LR8C	124	11.06	1.61	7.25	18.40	1.90	<0.0001	167	12.96	2.13	8.76	20.23
LR8D	104	13.13	1.68	10.08	19.01	1.50	<0.0001	124	14.63	2.01	10.43	20.33
LR8E	92	14.14	1.68	10.36	17.75	1.85	<0.0001	127	16.00	1.85	11.70	20.89
LR8F	102	16.09	1.82	11.95	21.93	1.76	<0.0001	92	17.84	2.14	12.96	22.96
LR8G	110	17.98	2.06	13.40	22.57	1.61	<0.0001	116	19.59	2.02	14.78	23.87
LR8H	200	20.13 (20.52)		13.28	22.54	1.37	<0.0001	267	21.50 (21.85)		15.56	23.87

To investigate the validity of t tests on this data, which depends on the data being normally distributed, the data for each TDS was checked using graphs and examining the difference between the means and medians. Graphs of TDS data distribution for several stages of the UL8 and LL8 are shown below (Figure 24) with a normal curve superimposed on the sample data. Where numbers of subjects are fewer in, for example, the Stage A data, the distribution is less likely to conform to a normal curve but as numbers increase the distribution appears to be more apparent. For the UL8 at Stage A, the graph suggests that this stage may be expected to be seen before the age of six in Black British individuals. Data for Stage H is not normally distributed as this represents the end stage of tooth development, and this is clearly shown in the relevant graph.

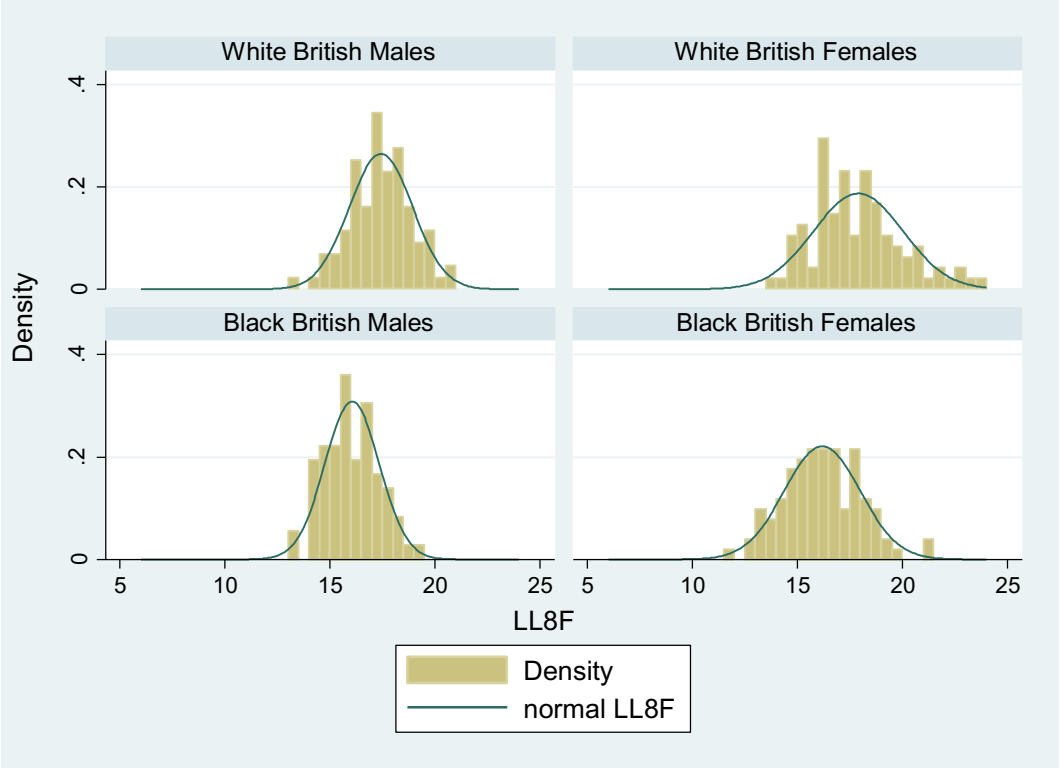


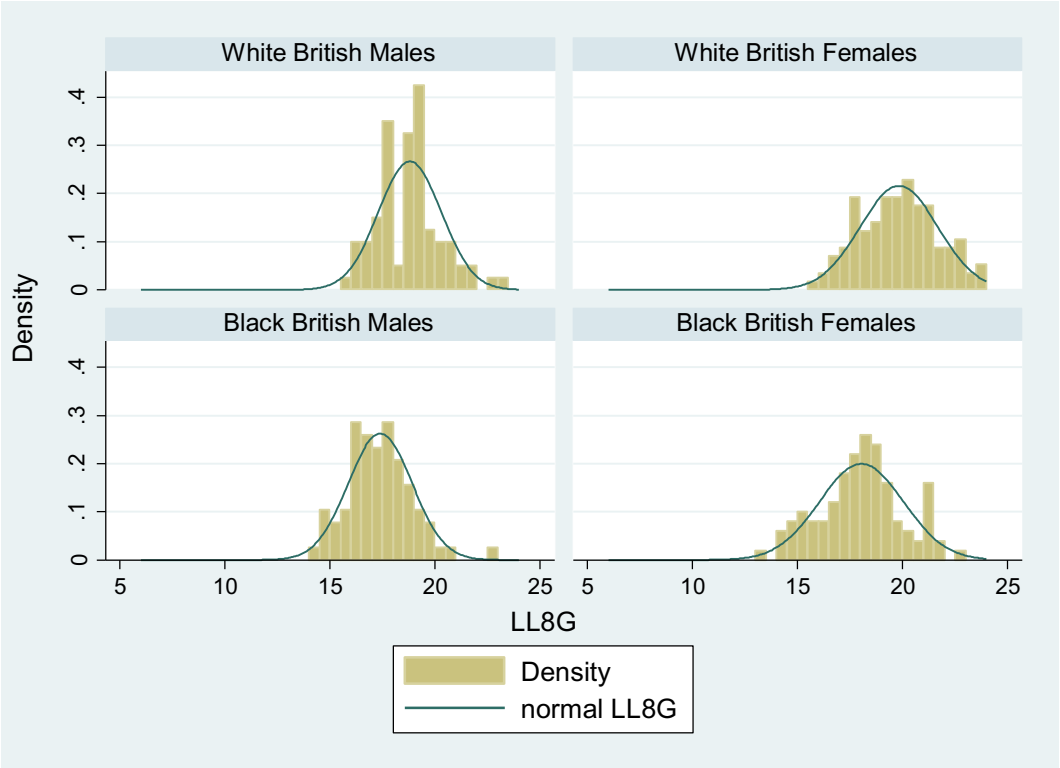

White British Males
White British Females
Black British Males
Black British Females
Density
0
.2
.4
.6
5
10
15
20
UL8B
Density
normal UL8B


White British Males
White British Females
Black British Males
Black British Females
Density
0
.2
.4
5
10
15
20
UL8C
Density
normal UL8C


White British Males
White British Females
Black British Males
Black British Females
Density
0
.1
.2
.3
5
10
15
20
UL8D
Density
normal UL8D


White British Males
White British Females
Black British Males
Black British Females
Density
0
.1
.2
.3
5
10
15
20
25
LL8E
Density
normal LL8E


White British Males
White British Females
Black British Males
Black British Females
Density
0
.2
.4
5
10
15
20
25
LL8F
Density
normal LL8F


White British Males
White British Females
Black British Males
Black British Females
Density
0
.1
.2
.3
.4
5
10
15
20
25
LL8G
Density
normal LL8G

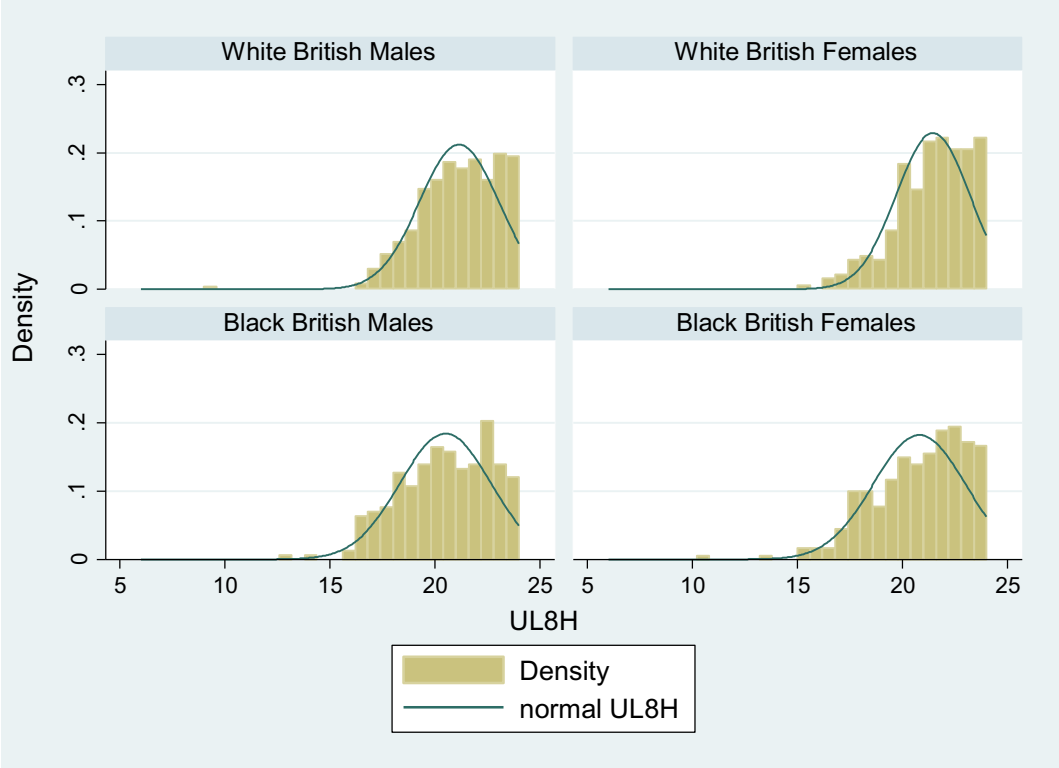


Figure 24. Graphs of TDS data distribution for the UL8 and LL8 with superimposed normal curve. Age in years is shown on x-axes.

The differences between means and medians for each Stage A-H for the LL8 are shown in Table 9. The small difference between the means and medians was a further assurance of normal distribution of the TDS age ranges.

However, Shapiro-Wilk tests were applied to the data for all TDS of UL8 and LL8 which includes the data shown in the Figure 24 and Table 9. The results are shown in Tables 10 and 11 where n is the number of subjects, W is the test statistic, and Prob>z is the p-value associated with the test statistic. If the p-value is less than 0.05, the null hypothesis of the test is rejected and there is sufficient evidence to say that the variable displacement is not normally distributed. The index V indicates departure from normality, with a value of 1 for a normal population and large values indicating nonnormality. The 95% critical values of V,

Table 9. Difference between means and medians for LL8 TDS A-H (Uncensored Stage H data).

	TDS	n	Mean	Median	Difference
	LL8A	33	8.486	8.674	-0.188
	LL8B	66	9.463	9.231	0.232
Black	LL8C	128	11.207	10.835	0.372
British	LL8D	82	12.856	12.712	0.144
Males	LL8E	100	14.444	14.270	0.174
	LL8F	72	16.051	15.852	0.199
	LL8G	77	17.387	17.333	0.054
	LL8H	260	20.595	20.704	-0.109
	LL8A	46	8.145	7.966	0.179
	LL8B	56	9.198	9.039	0.159
Black	LL8C	116	10.966	10.872	0.094
British	LL8D	96	12.957	12.738	0.219
Females	LL8E	120	14.262	14.396	-0.134
	LL8F	102	16.178	16.071	0.107
	LL8G	100	18.045	18.112	-0.067
	LL8H	302	20.931	21.291	-0.360
	LL8A	107	9.898	9.566	0.332
	LL8B	125	11.404	11.280	0.124
White	LL8C	184	12.829	12.819	0.010
British	LL8D	67	14.231	14.073	0.158
Males	LL8E	134	15.770	15.654	0.116
	LL8F	87	17.424	17.399	0.025
	LL8G	80	18.800	18.821	-0.021
	LL8H	373	21.244	21.451	-0.207
	LL8A	115	9.941	9.511	0.430
	LL8B	110	11.079	10.767	0.312
White	LL8C	180	12.815	12.742	0.073
British	LL8D	120	14.792	14.745	0.047
Females	LL8E	136	15.985	16.108	-0.123
	LL8F	95	17.894	17.533	0.361
	LL8G	114	19.830	19.837	-0.007
	LL8H	316	21.482	21.748	-0.266

which depend on the sample size, are between 1.2 and 2.4. While the Shapiro Wilk tests show that Stage H data is, as expected, not normally distributed, the same is shown for many other TDS. While raising wider questions about data used in RDS for DAE which is assumed to normally distributed, t tests which test normal data are still useful to investigate the ethnic differences in the present study.

Table 10. Shapiro Wilk Tests for UL8 TDS A-H with non-normal distribution results shaded.

	TDS	n	W	V	z	Prob>z
Black British Males	UL8A	14	0.94195	1.1	0.141	0.4439
	UL8B	51	0.92216	3.7	2.804	0.0025
	UL8C	100	0.94836	4.3	3.217	0.0007
	UL8D	122	0.99479	0.5	-1.515	0.9351
	UL8E	90	0.96048	3.0	2.415	0.0079
	UL8F	71	0.97274	1.7	1.151	0.1248
	UL8G	69	0.99293	0.4	-1.834	0.9667
	UL8H	263	0.97036	5.6	4.027	0.0000
Black British Females	UL8A	27	0.94467	1.6	0.999	0.1588
	UL8B	43	0.87972	5.0	3.413	0.0003
	UL8C	88	0.88719	8.4	4.682	0.0000
	UL8D	134	0.96393	3.8	3.015	0.0013
	UL8E	116	0.98287	1.6	1.054	0.1460
	UL8F	78	0.98410	1.1	0.145	0.4423
	UL8G	96	0.98436	1.2	0.490	0.3119
	UL8H	300	0.94412	11.9	5.814	0.0000
White British Males	UL8A	43	0.87100	5.4	3.561	0.0002
	UL8B	93	0.93532	5.0	3.568	0.0002
	UL8C	162	0.98735	1.6	1.03	0.1516
	UL8D	138	0.98687	1.4	0.796	0.2130
	UL8E	106	0.99074	0.8	-0.489	0.6876
	UL8F	101	0.98382	1.3	0.662	0.2541
	UL8G	94	0.99233	0.6	-1.125	0.8696
	UL8H	385	0.94524	14.6	6.363	0.0000
White British Females	UL8A	46	0.91321	3.8	2.846	0.0022
	UL8B	83	0.93204	4.8	3.448	0.0003
	UL8C	151	0.96192	4.5	3.389	0.0004
	UL8D	159	0.96559	4.2	3.268	0.0005
	UL8E	155	0.97015	3.6	2.891	0.0019
	UL8F	99	0.99012	0.8	-0.470	0.6809
	UL8G	111	0.97486	2.3	1.824	0.0341
	UL8H	308	0.95087	10.7	5.574	0.0000

Table 11. Shapiro Wilk Tests for LL8 TDS A-H with non-normal distribution results shaded.

	TDS	n	W	V	z	Prob>z
Black British Males	LL8A	33	0.97866	0.7	-0.658	0.7449
	LL8B	66	0.91795	4.8	3.407	0.0003
	LL8C	128	0.95992	4.1	3.158	0.0008
	LL8D	82	0.98721	0.9	-0.242	0.5955
	LL8E	100	0.97243	2.3	1.825	0.0340
	LL8F	72	0.99145	0.5	-1.347	0.9111
	LL8G	77	0.97929	1.4	0.7	0.2419
	LL8H	260	0.96889	5.8	4.114	0.0000
Black British Females	LL8A	46	0.89500	4.6	3.250	0.0006
	LL8B	56	0.94796	2.7	2.114	0.0173
	LL8C	116	0.95481	4.2	3.223	0.0006
	LL8D	96	0.95438	3.6	2.860	0.0021
	LL8E	120	0.98718	1.2	0.471	0.3189
	LL8F	102	0.99206	0.7	-0.900	0.8160
	LL8G	100	0.98689	1.1	0.175	0.4305
	LL8H	302	0.95156	10.4	5.494	0.0000
White British Males	LL8A	107	0.95645	3.8	2.976	0.0015
	LL8B	125	0.98580	1.4	0.778	0.2183
	LL8C	184	0.99516	0.7	-0.913	0.8194
	LL8D	67	0.98672	0.8	-0.515	0.6966
	LL8E	100	0.97243	2.3	1.825	0.0340
	LL8F	72	0.99145	0.5	-1.347	0.9111
	LL8G	77	0.97929	1.4	0.700	0.2419
	LL8H	373	0.96095	10.1	5.484	0.0000
White British Females	LL8A	115	0.94763	4.9	3.535	0.0002
	LL8B	110	0.96600	3.0	2.480	0.0066
	LL8C	180	0.99109	1.2	0.441	0.3296
	LL8D	120	0.97861	2.1	1.617	0.0529
	LL8E	136	0.98740	1.3	0.675	0.2499
	LL8F	95	0.96307	2.9	2.372	0.0089
	LL8G	114	0.98642	1.3	0.501	0.3082
	LL8H	316	0.94611	12.0	5.852	0.0000

The age ranges at third molar TDSs are wide for both ethnic groups (Table 12).

Table 12. Table of age ranges in years at each LL8 TDS for whole sample.

	Range in Years for each TDS for Whole Sample (Max-Min) using censored data for Stage H			
TDS	Black British Males	Black British Females	White British Males	White British Females
UR8A	5.38	3.86	8.51	6.62
UR8B	4.24	5.62	8.16	11.24
UR8C	6.95	7.13	8.91	10.28
UR8D	8.11	9.43	13.93	10.59
UR8E	9.97	8.62	8.89	9.55
UR8F	6.44	7.89	8.42	8.81
UR8G	8.38	11.38	7.02	8.35
UR8H	5.50	10.55	12.31	8.11
UL8A	3.08	5.43	8.44	5.56
UL8B	6.29	7.71	7.23	10.95
UL8C	7.50	11.64	11.50	12.14
UL8D	8.91	8.23	10.79	10.59
UL8E	8.59	8.38	9.72	10.42
UL8F	6.95	7.89	8.42	9.90
UL8G	7.55	11.17	7.44	8.54
UL8H	7.56	13.16	12.31	8.31
LL8A	4.25	5.99	8.29	7.48
LL8B	6.04	5.28	9.18	8.43
LL8C	7.33	11.15	9.39	9.80
LL8D	8.11	8.66	8.99	9.90
LL8E	8.16	8.02	10.76	11.30
LL8F	6.30	9.54	7.68	9.90
LL8G	8.44	9.60	7.65	7.87
LL8H	9.74	9.66	6.56	8.11
LR8A	5.78	6.25	9.88	6.88
LR8B	5.93	5.23	9.18	9.61
LR8C	7.08	11.15	9.20	11.47
LR8D	8.48	8.93	7.62	9.90
LR8E	7.00	7.39	10.76	9.19
LR8F	6.30	9.98	7.68	10.00
LR8G	8.18	9.17	7.65	9.09
LR8H	5.31	9.26	7.12	8.31

Box and whisker plots (Figures 25 and 26) show the distribution of age around the median for each LL8 TDS for males and females respectively with every TDS occurring at a younger age in the Black British group compared to the White British group. The box represents the middle 50% of results, the inter-quartile range, with the median shown by the central bar; and the whiskers can extend to 1.5 times the interquartile range from the nearer quartile. The dots outside the whiskers represent any values that are less or more than 1.5 times the inter-quartile range from the nearer quartile. As the results in Tables 7 and 8 also show, this pattern of development occurring at a younger age in the Black British group compared to the White British group is apparent in both males and females and for all four third molars.

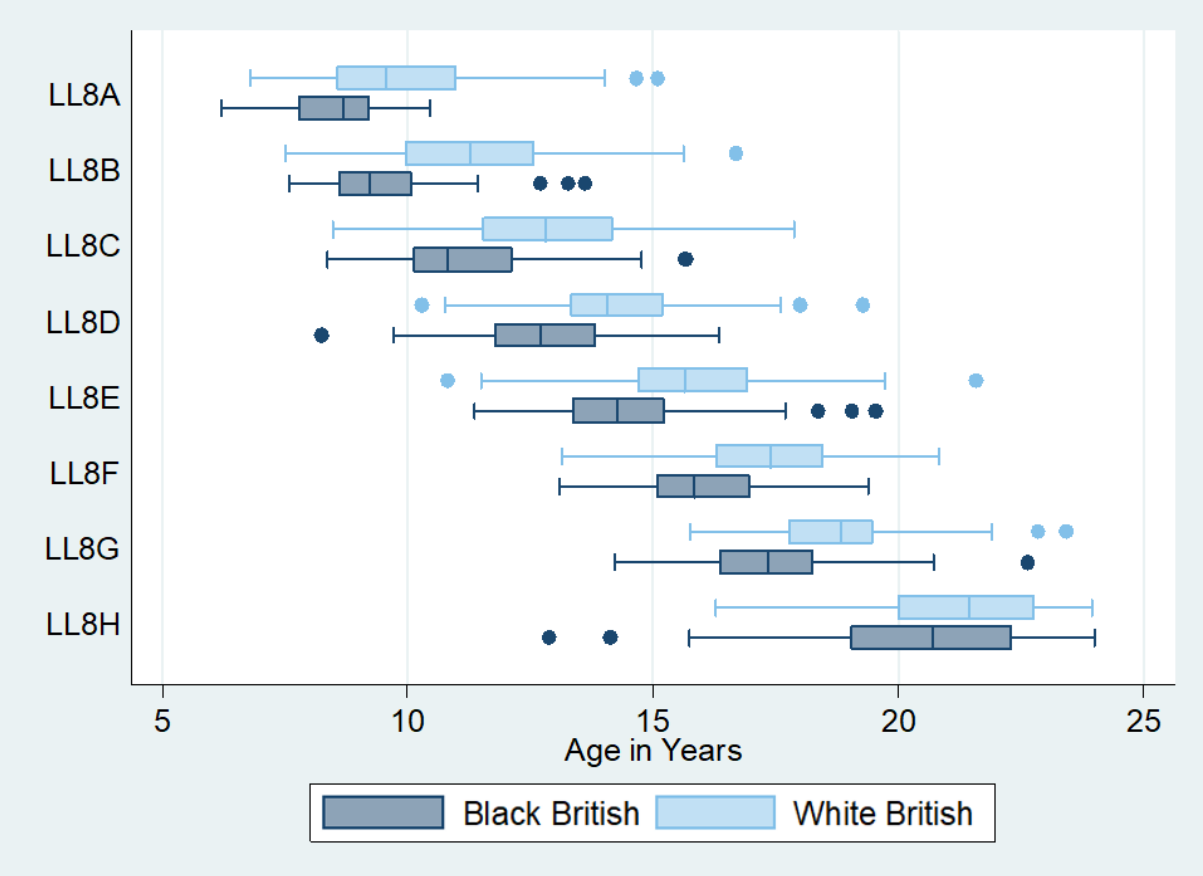


Figure 25. Distribution of age of males with lower left third molars at Stages A-H

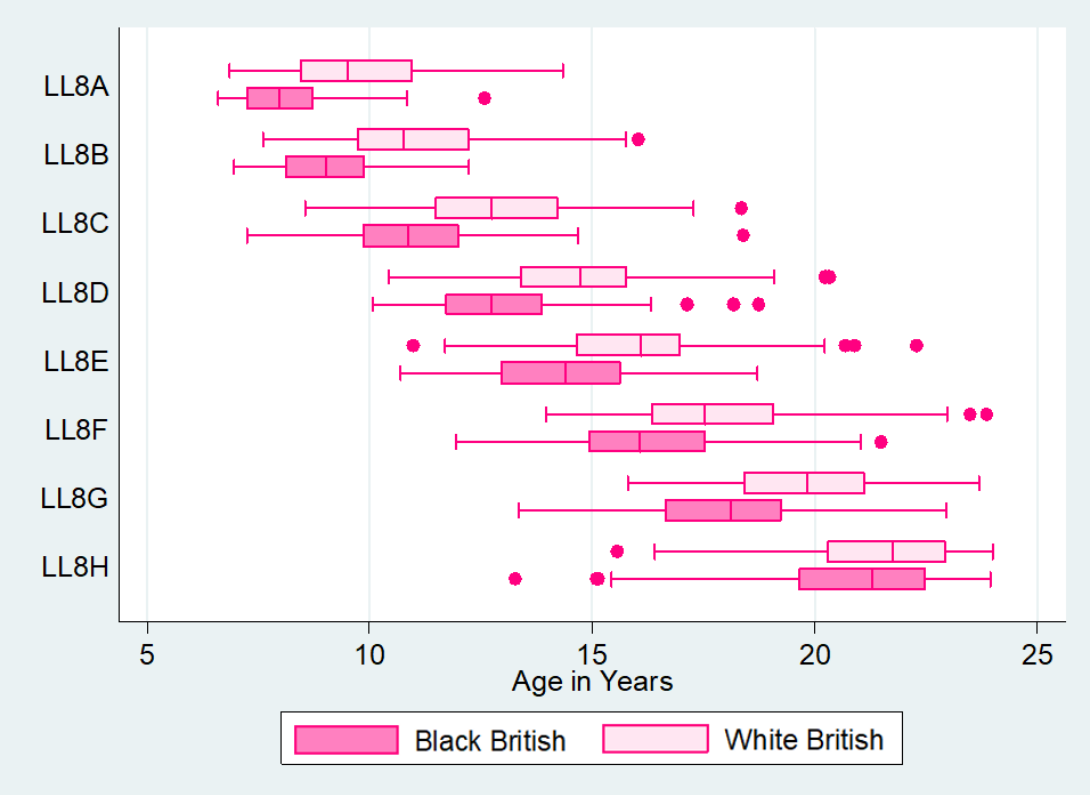


Figure 26. Distribution of age of females with lower left third molars at Stages A-H

When comparing the two ethnic groups, either Black British with White British males (Figure 25) or Black British with White British females (Figure 26), each TDS is seen to occur at a younger age in Black British subjects.

The differences in LL8 development between males or females when comparing the two ethnicities also show that the difference in timing of the TDSs is greatest during the middle TDSs with the difference appearing less at the earlier and later stages. The widest difference between TDS timing occurs around the age of 11 for boys and 13 for girls.

When males and females of the same ethnic group are compared, that is, Black British males with females (Figure 27), or White British males with females (Figure 28), a pattern is seen in both ethnic groups where the earlier stages of LL8 development are achieved at a younger age by females compared to males, but the males later overtake the females in LL8 development and the later stages are achieved at a younger age by males.

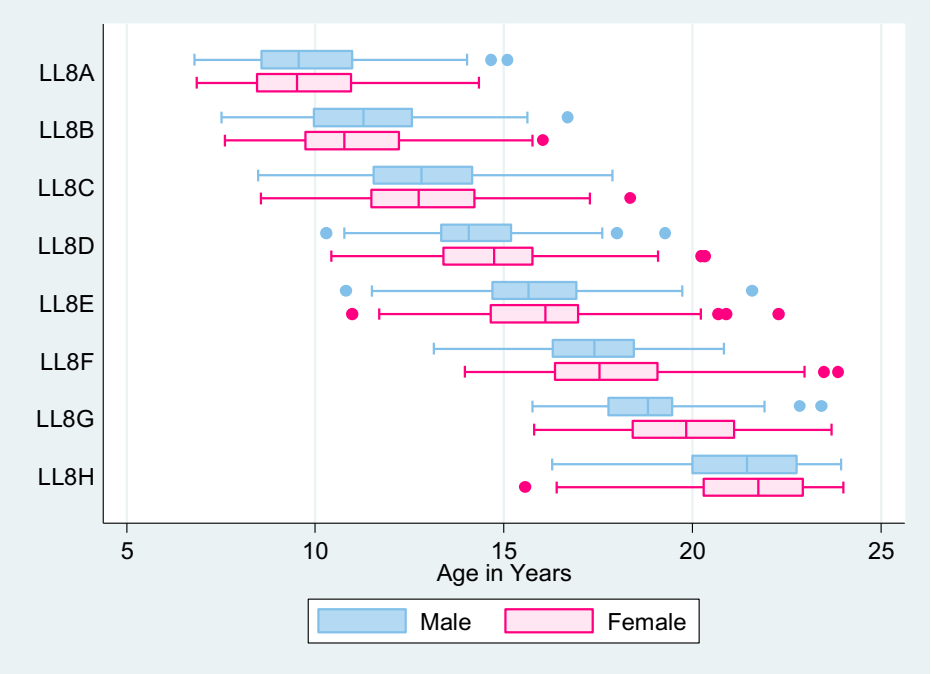


Figure 27. Distribution of age of White British males and females with lower left third molars at Stages A-H

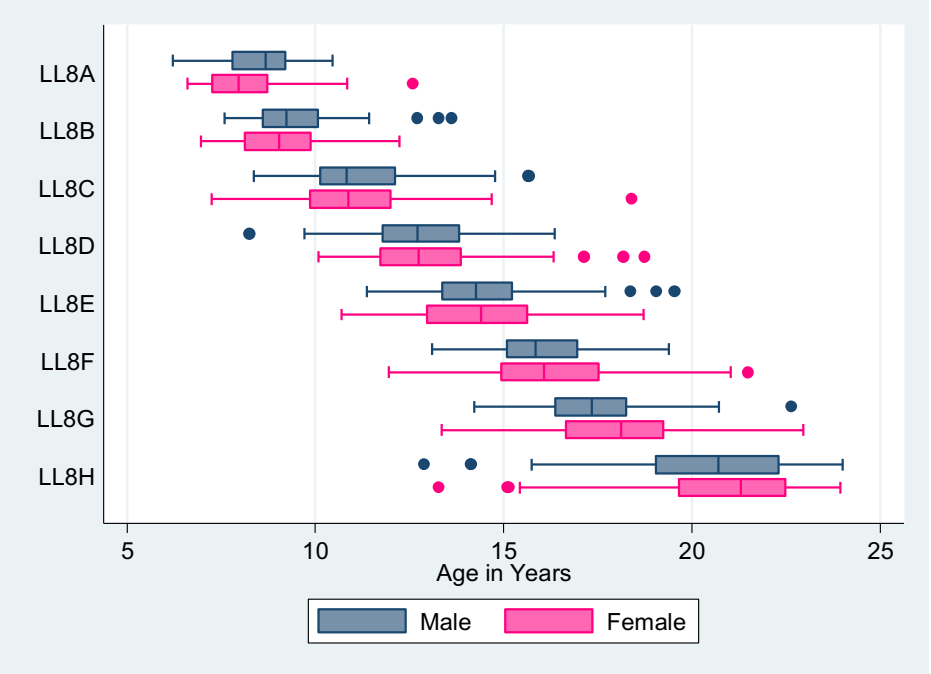


Figure 28. Distribution of age of Black British males and females with lower left third molars at Stages A-H

This agrees with the general consensus that third molars develop at a younger age in males compared to females but the results also show that while this is true at the completion of third molars, this pattern in each respective ethnicity is not seen throughout the whole development of these teeth. An acceleration in third molar development in males compared to females is apparent and, from the graphs in Figures 27 and 28, the period when males overtake females in LL8 development can be said to occur at approximately 12 years of age in the Black British group and approximately 13 years of age in the White British group.

Box and whisker plots of the ages for each LL8 TDS for all the four groups, Black British and White British males and females, are all shown together in Figure 29. This graph illustrates how LL8 development occurs at a younger age in both male and female Black British subjects compared to their White British counterparts, and also occurs at a younger age in females compared to males in both ethnic groups.

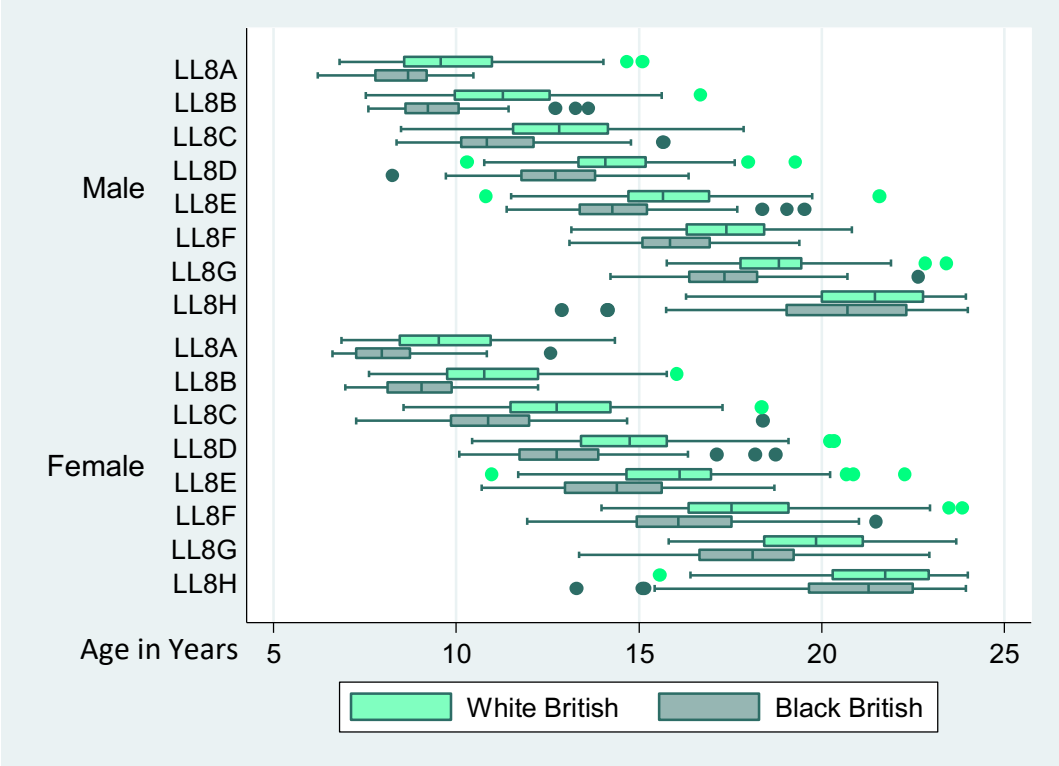


Figure 29. Graph to show ages for Stages A-H in Black British and White British males and females.

The next graph (Figure 30) shows age ranges for four LL8 TDS D-G in the four groups: males and females of both ethnic groups. The groups have been arranged in order of the timing of LL8 development. White British females' LL8 TDSs are seen at a later age than in any other group and this is shown at the top. Below the White British females are the White British males, then Black British females, followed by Black British males who have the youngest ages at LL8 TDSs compared to the other groups. This same pattern is seen for all TDSs of the LL8.

Figure 30. Graph to show ages for stages D, E, F & G in males and females of both ethnic groups in order of timing of development of LL8.

4.2 Percentages of Third Molar TDS seen in Year Groups

Stacked bar charts can be used to illustrate the percentages of, for example, LL8 TDS A-H seen in a certain age group. Based on a particular year group, these results give a different

perspective compared to comparing average ages for each TDS as has been so far considered above. This way of illustrating the data is relevant because of the claims made in DAE which, dismissing ethnic factors, rest on the chances of being 18 or over when a third molar is at Stage H. For example, a chance of 90.1% for males, 92.2% for females [240], or an overall 95% chance, and the deduction that, on the balance of probabilities, over 18 if a lower third molar is at Stage G or H [241].

The differences in the timing of lower left third molar (LL8) development between males of the two ethnic groups are illustrated in Figure 31 which shows the percentages of each TDS in 17-year-old males. 37% of LL8s in the Black British group and 17% in the White British group were at Stage H. In Black British 17-year-old males, 75% of LL8s were at Stages G or H while this figure was 43% in the White British group. Figure 32 illustrates the results for LL8 TDS for 18-year-old males showing that the majority of LL8s, 62%, have reached developmental completion in this age group of Black British males whilst 40% of LL8 are at Stage H in the White British group. These ages are most relevant to DAE at the 18-year-old threshold and clearly illustrate an ethnic difference with males of British Black ethnicity showing development of LL8 occurring at a younger age compared to the White British.

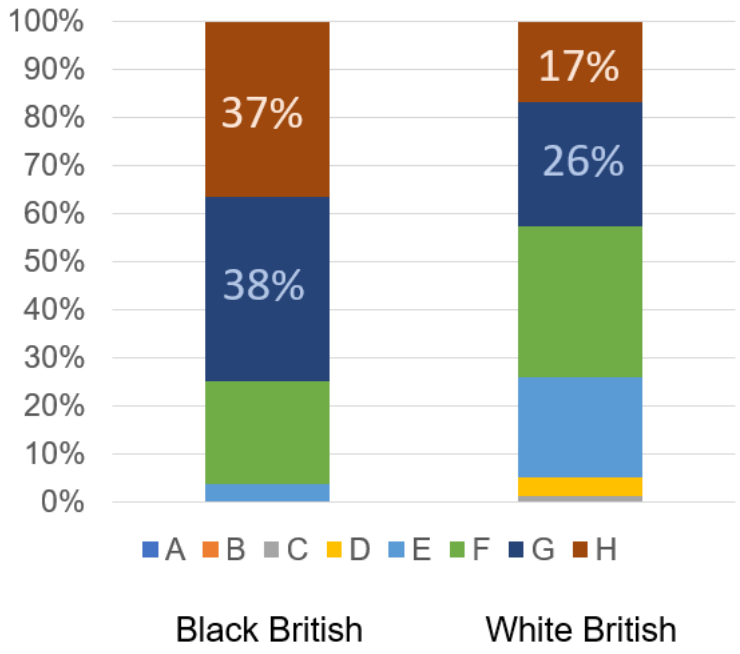


Figure 31. Percentage of Stages A-H in lower left third molars in 17-year-old males

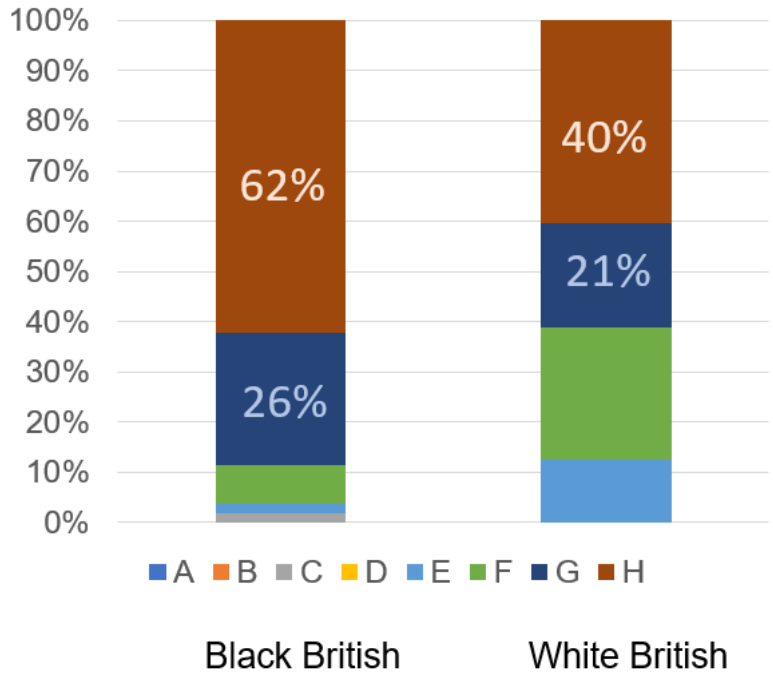


Figure 32. Percentage of Stages A-H in lower left third molars in 18-year-old males

These stacked bar charts can be arranged to show the whole age range of the sample. The following four graphs (Figures 33, 34, 35 and 36) show the percentages of each TDS for the LL8 in males and females of each ethnic group.

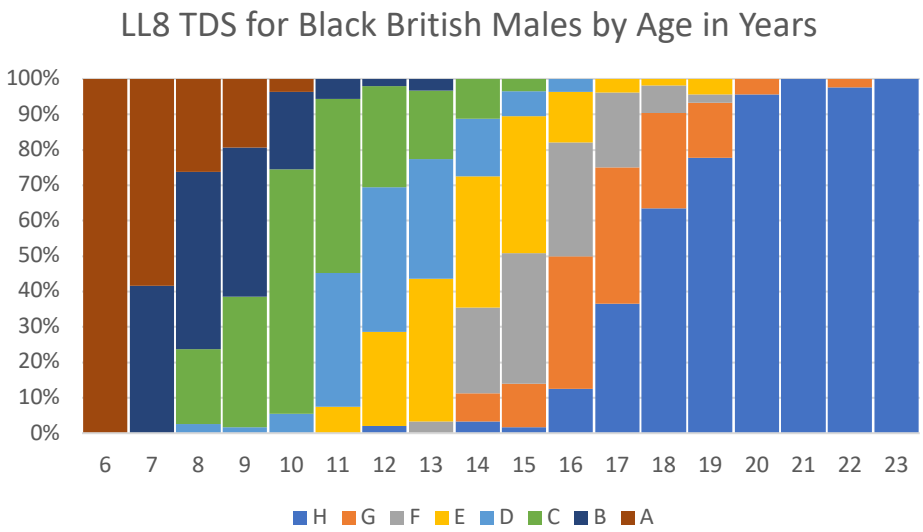


Figure 33. Stacked bar chart for LL8 TDSs in 6-24 year-old Black British males

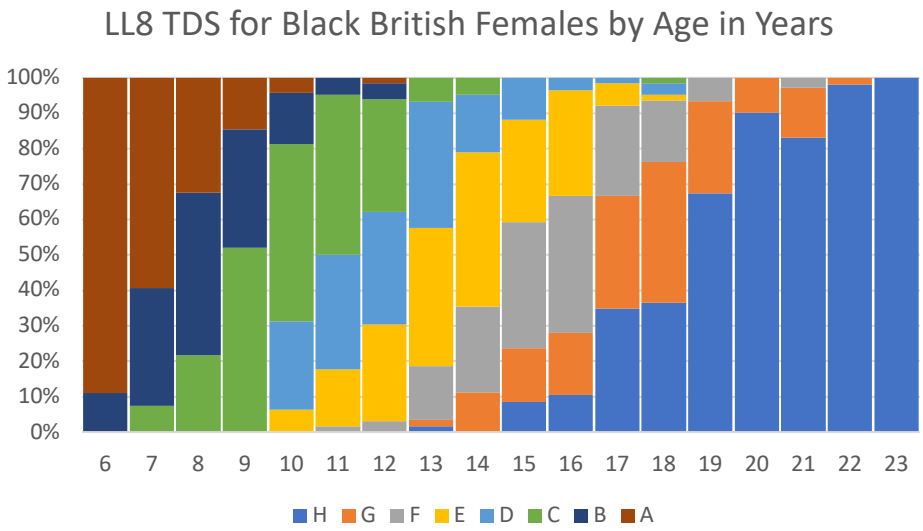


Figure 34. Stacked bar chart for LL8 TDSs in 6-24 year-old Black British females

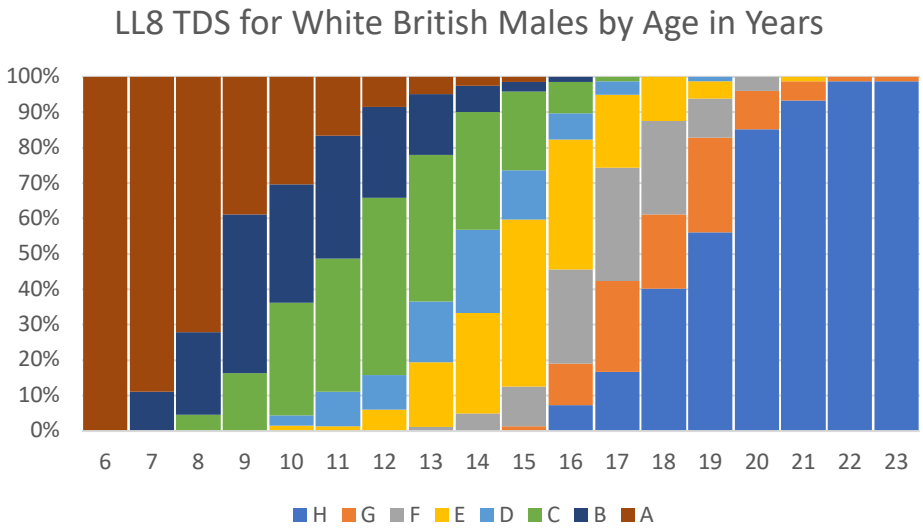


Figure 35. Stacked bar chart for LL8 TDSs in 6-24 year-old White British males

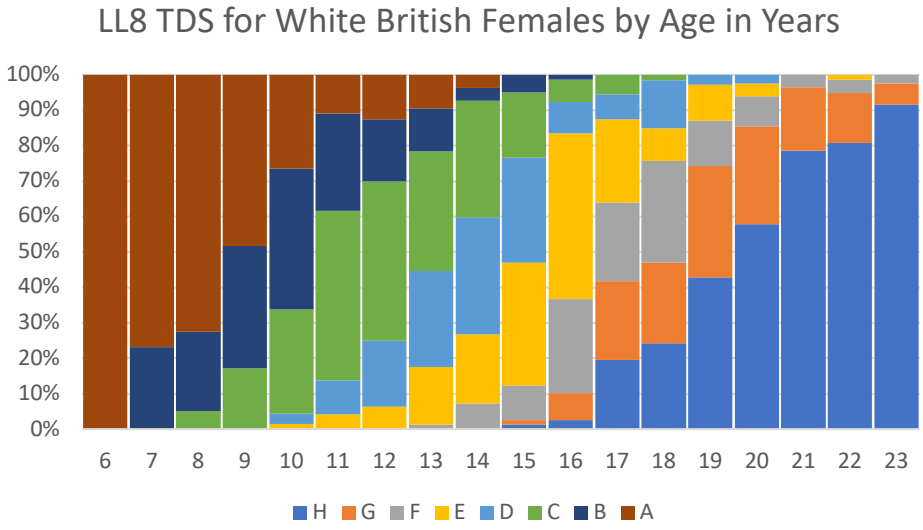


Figure 36. Stacked bar chart for LL8 TDSs in 6-24 year-old White British females

Figure 37 shows the above four graphs together to allow visual comparison to illustrate the ethnic difference of LL8 development stages occurring at a younger age in Black British subjects compared to White British, and also at younger ages in males compared to females.

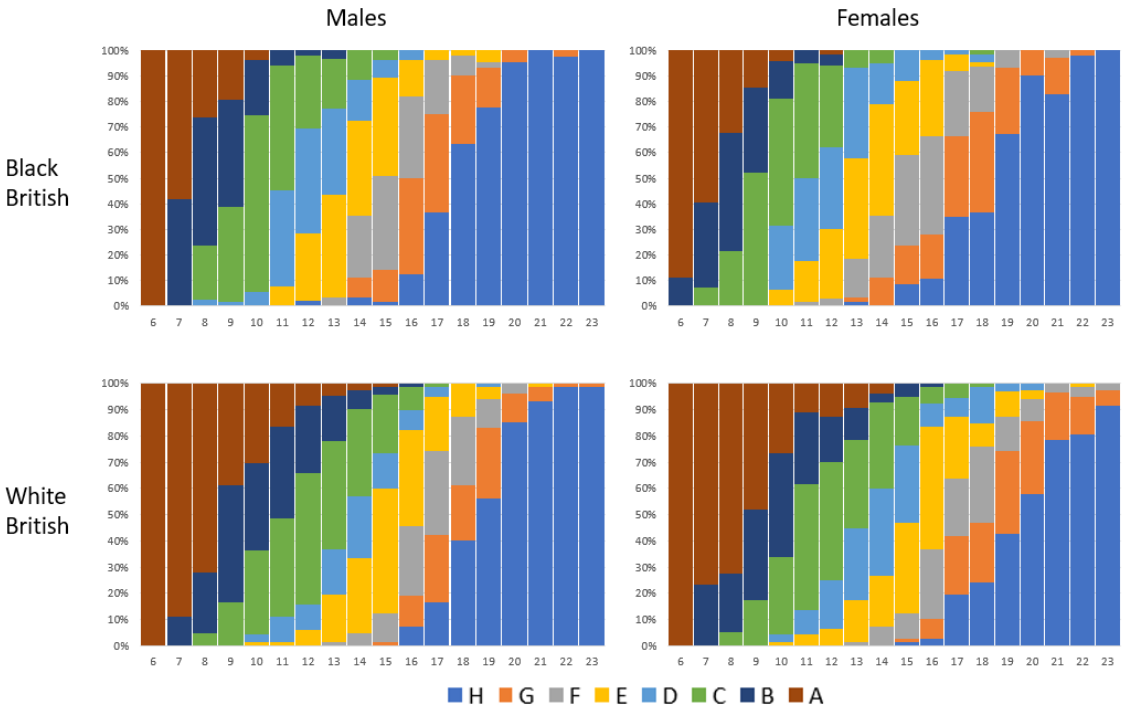


Figure 37. Stacked bar charts for LL8 TDSs in 6-24 year-old Black British and White British males and females by age in years for comparison

4.3 Six-year-olds in the sample

The sample was intended to show the whole development of the third molar. In some subjects at the lower age limit, third molar development had already begun. DPTs for 6-year-olds were limited in the Romexis® database and so subject numbers small at this age. Even so, the percentages of the LL8 at Stages A, B and C in males and females of each ethnicity in 6-year-olds are shown in Table 13 indicating initiation of LL8 development at a younger age in the Black British group. Chi-squared tests showed that these differences were statistically significant for Stage A (p=0.003 for males and 0.023 for females).

Table 13. Percentages of LL8 at Stages A, B and C in six-year-olds

	n	Stage A	Stage B	Stage C
Black British Male	13	23% (n=3)	0% (0)	0% (0)
Black British Female	17	47% (n=8)	6% (n=1)	0% (0)
White British Male	75	3% (n=2)	0% (0)	0% (0)
White British Female	80	1% (n=1)	0% (0)	0% (0)

4.4 Third Molar Agenesis

To address the second null hypothesis that TMA is the same in Black British and White British ethnic groups, an analysis of the frequency of TMA, taking into account the pattern of TMA by quadrants, is presented.

Only subjects aged between 12 and 19 years were included in the analysis for TMA to minimise the possibility of counting late-developing third molars as developmentally absent, and to allow for any evidence of third molar removal in older subjects to be observed on the radiograph on the basis that it is highly unlikely for third molars to be removed before the age of 18 but, if they had been, radiographic evidence is likely to be visible for one year after this event.

Having removed subjects <12 and >=20 years old from the study sample, 1,600 White British and 995 Black British subjects remained for TMA analysis (Table 14).

Table 14. Ethnicity and sex distribution of 12.00-19.99 year-olds.

	Male	Female	**Total**
White British	800	800	**1,600**
Black British	473	522	**995**
Total	**1,273**	**1,322**	**2,595**

First, the data for third molars was analysed to show how many of each third molar were present or developmentally missing.

These results were achievable using the codes, as explained in Chapter 3, for each tooth in the dentition, including the third molars, as follows: 1) Present; 2) Extracted; 3) and 4) developmentally missing; 5) Unable to see on DPT because of limited image such as, for example, when only one side of the dentition is shown on a partial DPT; and 6) Present but image poor and unusable for TDS assessment. This means that third molars coded 1, 2 and 6 together represent those that are present, i.e., no TMA; those coded 3 and 4 are developmentally missing, i.e., show TMA; and those coded 5 are unaccountable.
Using these codes, the results in Table 15 were obtained and show the numbers of each third molar present including in this number any that were found to have been previously extracted, developmentally absent (TMA), or not visible because of a limited image. All third molars in the sample of 2,595 subjects are therefore accounted for. These results are followed by Table 16 which shows percentages of TMA or presence of each third molar for males and females of both ethnic groups.

Table 15. Third molars present and missing in 12.00-19.99 year-olds.

		Total Present	Total TMA	Not on Image	Total
UR8	WB MALE	622	161	17	800
	WB FEMALE	612	171	17	800
	BB MALE	431	21	21	473
	BB FEMALE	480	21	21	522
UL8	WB MALE	641	148	11	800
	WB FEMALE	621	171	8	800
	BB MALE	443	17	13	473
	BB FEMALE	491	21	10	522
LL8	WB MALE	622	168	10	800
	WB FEMALE	614	179	7	800
	BB MALE	441	19	13	473
	BB FEMALE	488	25	9	522
LR8	WB MALE	620	164	16	800
	WB FEMALE	596	188	16	800
	BB MALE	431	22	20	473
	BB FEMALE	476	27	19	522

Table 16. Percentages of third molars present, missing, and not shown in 12 -20 year-olds

		%Present	%TMA	% Not on Image	% Total
UR8	WB MALE	77.75	20.13	2.13	100
	WB FEMALE	76.50	21.38	2.13	100
	BB MALE	91.12	4.44	4.44	100
	BB FEMALE	91.95	4.02	4.02	100
UL8	WB MALE	80.13	18.50	1.38	100
	WB FEMALE	77.63	21.38	1.00	100
	BB MALE	93.66	3.59	2.75	100
	BB FEMALE	94.06	4.02	1.92	100
LL8	WB MALE	77.75	21.00	1.25	100
	WB FEMALE	76.75	22.38	0.88	100
	BB MALE	93.23	4.02	2.75	100
	BB FEMALE	93.49	4.79	1.72	100
LR8	WB MALE	77.50	20.50	2.00	100
	WB FEMALE	74.50	23.50	2.00	100
	BB MALE	91.12	4.65	4.23	100
	BB FEMALE	91.19	5.17	3.64	100

This table shows the very marked ethnic difference in TMA for third molars which ranges between 18.50%-21.00% in White British males, 21.38%-23.50% in White British females, 3.59%-4.65% in Black British males, and 4.02%-5.17% in Black British females.

To find out the pattern of third molars affected by TMA, subjects with DPTs where any third molar areas are not shown were removed from the sample. These subjects are represented by the grey columns in Tables 15 and 16. Having removed these subjects, this leaves a sample of 2,480 who have four third molars known to be with or without TMA (Table 17).

Table 17. Ethnicity and sex distribution of 12.00-19.99 year-olds with all four third molar areas visible on DPT radiograph.

	Male	Female	**Total**
White British	773	776	**1,549**
Black British	439	492	**931**
Total	**1,212**	**1,268**	**2,480**

One, two, three, or all four third molars may be present or developmentally missing and there are 16 combinations of these variations. The number of subjects showing these combinations are shown in Tables 18-20.

Table 18. Numbers of subjects with all four third molars present (no TMA) or one developmentally missing third molar.

Third Molar Status		UR8 UL8 / LR8 LL8	**TMA** UL8 / LR8 LL8	UL8 **TMA** / LR8 LL8	UR8 UL8 / LR8 **TMA**	UR8 UL8 / **TMA** LL8
		NO TMA	TMA of UR8	TMA of UL8	TMA of LL8	TMA of LR8
White British	Male	525	19	14	14	12
	Female	514	13	10	13	18
Black British	Male	404	5	2	0	4
	Female	438	11	9	4	4

Table 19. Numbers of subjects with two developmentally missing third molars

Third Molar Status		UR8 UL8 / **TMA** **TMA**	**TMA** **TMA** / LR8 LL8	UR8 **TMA** / LR8 **TMA**	**TMA** UL8 / **TMA** LL8	UR8 **TMA** / **TMA** LL8	**TMA** UL8 / LR8 **TMA**
		TMA of LOWER 8'S	TMA of UPPER 8'S	LEFT SIDE TMA	RIGHT SIDE TMA	TMA of UL8 & LR8	TMA of UR8 & LL8
White British	Male	38	25	0	2	1	3
	Female	31	34	3	3	2	1
Black British	Male	7	5	0	0	0	1
	Female	13	3	1	0	0	0

Table 20. Numbers of subjects with three or four developmentally missing third molars

Third Molar Status		UR8 **TMA** / **TMA** **TMA**	**TMA** UL8 / **TMA** **TMA**	**TMA** **TMA** / LR8 **TMA**	**TMA** **TMA** / **TMA** LL8	**TMA** **TMA** / **TMA** **TMA**
		TMA of UL8, LL8 & LR8	TMA of UR8, LL8 & LR8	TMA of UR8, UL8 & LL8	TMA of UR8, UL8 & LR8	TMA (All 8's missing)
White British	Male	9	11	8	7	84
	Female	14	12	1	4	103
Black British	Male	1	1	0	0	8
	Female	2	1	0	2	4

Most subjects have all four third molars present although the marked ethnic difference is again shown. For White British, the next most frequent combination is all four third molars developmentally missing, i.e., total TMA, followed by both lower third molars missing, followed by both upper third molars missing. The least frequent combinations are unilateral TMA, diagonal TMA, and one missing third molar and this is true for both ethnic groups. In the Black British group, total TMA frequency was found to be similar to that of TMA of two

third molars. The numbers and percentages of subjects with TMA affecting none, one two, three, or all four third molars are summarised in Tables 21 and 22, and Figure 38.

Table 21 and 22. Numbers and percentages of subjects with TMA affecting none, one two, three, or all four third molars.

		Number of Missing Third Molars (n)					
		0	1	2	3	4	Total
White British	Male	525	35	69	59	84	772
	Female	514	31	74	54	103	776
Black British	Male	405	2	13	11	8	439
	Female	438	5	17	28	4	492

		Number of Missing Third Molars (%)					
		0	1	2	3	4	Total
White British	Male	68.0	4.5	8.9	7.6	10.9	100.0
	Female	66.2	4.0	9.5	7.0	13.3	100.0
Black British	Male	92.2	0.5	3.0	2.5	1.8	100.0
	Female	89.0	1.0	3.5	5.7	0.8	100.0

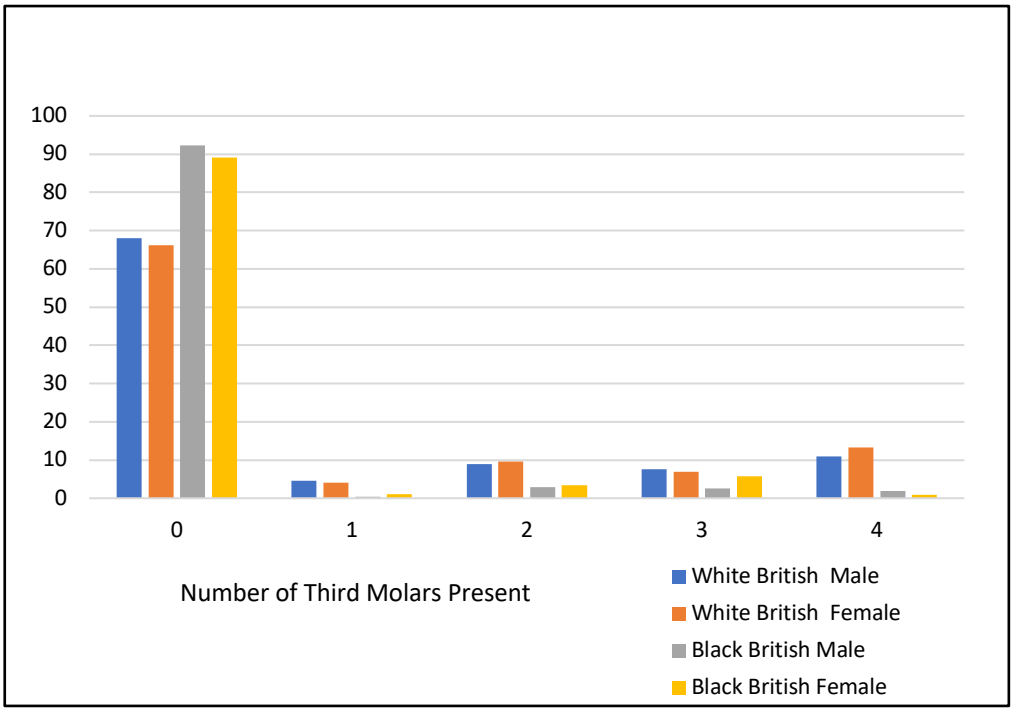


Figure 38. Bar Graph to show percentages of subjects with TMA affecting none, one two, three, or all four third molars.

The frequency of TMA of at least one third molar is seen in Table 23. TMA is more prevalent in females compared to males but this difference is slight. In Black British males and females respectively, 8% and 11% showed one or more missing third molar. White British showed significantly more TMA with 32% and 34% of males and females respectively showing one or more missing third molars.

Table 23. Numbers and percentages of 12.00-19.99 year-old subjects with zero or at least one developmentally missing third molar.

		Missing Third Molars (n)		
		0	1 or more	Total
White British	Male	525	247	772
	Female	514	262	776
Black British	Male	404	34	438
	Female	438	54	492
		Missing Third Molars (%)		
		0	1 or more	Total
White British	Male	68.01	31.99	100
	Female	66.24	33.76	100
Black British	Male	92.24	7.76	100
	Female	89.02	10.98	100

Using the numbers of Black British and White British with and without TMA as shown in Tables 23 and 24, the Odds Ratio of having at least one missing third molar for White British compared to Black British is 5.6:1 in males and 4.1:1 in females. Pearson's Chi-squared test was applied to the data for at least one missing third molar against no third molar agenesis in the two ethnic groups and showed that there is marked ethnic difference ($p < 0.0001$) in males and in females.

Table 24. 12.00-19.99 yr-olds (all third molars accountable) with and without TMA.

Males (n)	no TMA	TMA
BB	404	34
WB	525	247

Females (n)	no TMA	TMA
BB	438	54
WB	514	262

4.5 Hypodontia

The third null hypothesis is that the prevalence of hypodontia is the same in Black British and White British ethnic groups.

Hypodontia is associated with delay in development of the remaining teeth [116]. GSTT is a centre for the treatment of hypodontia. To find out if hypodontia could, at least in part, be influencing the ethnic difference shown in the sample as a whole, e.g., if it could be explained by a greater incidence of hypodontia in the White British compared to Black British group, results regarding hypodontia will be presented.

The codes for Dentition Status were 1) Complete permanent dentition; 2) All permanent teeth present except one or more third molars (TMA only); 3) Hypodontia (one to five permanent teeth developmentally missing not including third molars) and TMA; 4) Oligodontia (more than five permanent teeth developmentally missing not including third molars) and TMA; 5) Hypodontia only (and no TMA); 6) Oligodontia only (and no TMA); 7) Unsure (e.g. if history of missing teeth not available or third molars may still develop); and 8) Other (Obvious conditions identifiable from the DPT, e.g. cleft palate, which may affect dental development). Subjects with a Dentition Status of Codes 1 or 2, denoting a complete dentition or TMA only, have no hypodontia. Subjects with hypodontia of any severity, with or without TMA, have Dentition Status Codes of 3, 4, 5 or 6. Other subjects have Dentition Statuses of Codes 7 or 8, denoting subjects in whom hypodontia or TMA could not be ascertained with certainty. The results for subjects known to have, or not have, hypodontia in the whole sample of 5,590 are shown in Table 25.

Table 25. Prevalence of subjects known to be with or without hypodontia in whole sample (n=5,590)

	With hypodontia	No hypodontia	Total with or without hypodontia	% With hypodontia
White British Male	344	988	1332	25.83
White British Female	368	957	1325	27.77
Black British Male	71	635	706	10.06
Black British Female	100	649	749	13.35

The prevalence of hypodontia is greater in the White British group compared to the Black British group and is slightly higher in females of both ethnic groups. In the White British group, 26% of males and 28% of females have hypodontia compared to 10% and 13% of Black British males and females respectively.

With regard to complete dentitions, applying the Dentition Status codes to the whole sample, the numbers of subjects with complete dentitions and hypodontia with or without TMA were found and are shown in Table 26. The prevalence of complete dentitions, that is, subjects with all permanent teeth present, in Black British males and females is 80% and 76% respectively and in White British males and females is 49% and 48% respectively. These figures reflect the results for complete dentitions found in 12.00-19.99 year-olds (Table 18).

Table 26. Prevalence of subjects with complete dentitions in whole sample (n=5,590)

	Number of Subjects with Complete Dentitions	Number of Subjects with Hypodontia +/- TMA	Total	% of subjects with Complete Dentitions
White British Male	648	1332	1980	48.65
White British Female	633	1325	1958	47.77
Black British Male	562	706	1268	79.60
Black British Female	568	749	1317	75.83

Using data collected about Dentition Status, the incidence of TMA when associated with other missing teeth, i.e., hypodontia of varying severity, was then investigated. Having removed 342 subjects because their Dentition Status codes were 7 or 8, denoting Unsure or Other, the results for the group of 2138 subjects aged 12.00–19.99 years and with all four molars accountable on their DPT are shown in Table 27.

Table 27. Dentition Status of 12.00-19.99 Year-Olds with All Four Third Molars Accountable

	12.00-19.99 year-olds with all third molars accountable (n and %(shaded))					
	Complete Dentition	TMA ONLY	Hypodontia +TMA	Oligodontia +TMA	Hypodontia ONLY	Oligodontia ONLY
	1	2	3	4	5	6
White British male	375	74	65	76	83	7
White British female	366	78	86	70	64	4
Black British male	317	14	6	7	32	1
Black British female	330	21	17	4	38	3
White British male	55.15	10.88	9.56	11.18	12.21	1.03
White British female	54.79	11.68	12.87	10.48	9.58	0.60
Black British male	84.08	3.71	1.59	1.86	8.49	0.27
Black British female	79.90	5.08	4.12	0.97	9.20	0.73

Hypodontia and oligodontia per se, i.e., developmentally missing teeth other than third molars is shown to be much higher in the White British group and oligodontia, i.e., six or more missing teeth other than third molars, is seen to be very likely to occur in association with missing third molars. In the Black British group, in complete contrast to the White British group, hypodontia of any severity is seen to be about twice as likely without TMA. The results in general have shown a much greater prevalence of all developmentally missing teeth, TMA or hypodontia of any severity, in the White British group compared to the Black British group.

Table 28 summarises the above observations and gives percentages of subjects with TMA associated with or without hypodontia of any degree of severity, that is, at least one other developmentally missing permanent tooth excluding the third molars. Approximately 80% of the Black British group compared to approximately 55% of the White British group have complete dentitions with all permanent teeth including third molars present. TMA with or without hypodontia is slightly more prevalent in females than males as previously shown and an ethnic difference is apparent with 32% and 7% of White British males and Black British males respectively with TMA and 35% and 10% of White British females and Black British females with TMA respectively. These results confirm the ethnic difference seen when results for presence or absence of each third molar were calculated. About 14% of the Black British group, compared to about 33% of the White British, show hypodontia of any severity. As mentioned above, there is a marked ethnic contrast with the Black British with hypodontia

being more likely to be without TMA, while the White British with hypodontia are more likely to have TMA.

Table 28. Percentages of 12.00-19.99 year-olds (all third molars accountable) with Complete Dentitions, TMA, and other missing teeth, i.e., any degree of hypodontia.

	Percentages of 12.00-19.99 year-olds with Complete Dentitions, TMA, and other missing teeth, i.e. any degree of hypodontia				
	COMPLETE DENTITION	TMA ONLY	TMA with hypodontia	TMA with or without hypodontia	HYPODONTIA ONLY (no TMA)
White British male	55.15	10.88	20.74	31.62	13.24
White British female	54.79	11.68	23.35	35.03	10.18
Black British male	84.08	3.71	3.45	7.16	8.75
Black British female	79.90	5.08	5.08	10.17	9.93

The results from Table 27 are shown for White British males in Table 29 in order to find the likelihood of subjects having hypodontia with or without TMA.

Table 29. White British male 12.00-19.99 year-olds with TMA and/or hypodontia.

White British males	**no TMA**	**TMA**	Total
No Hypodontia	375	74	449
Hypodontia	90	141	231
Total	465	215	**680**

141 out of 680 (0.2074) White British males have hypodontia with TMA, and 90 out of 680 (0.1324) have other missing teeth with no TMA. This gives a ratio of TMA and hypodontia to no TMA and hypodontia of 1.6:1.

Out of 680 White British males, 231 have varying degrees of hypodontia, and 141 have hypodontia with TMA. The probability that White British males have TMA when there are other developmentally missing teeth, i.e., P(TMA/hypodontia), is 61%.

$$P(\text{TMA/ hypodontia}) = \frac{P(\text{TMA, hypodontia})}{P(\text{hypodontia})}$$

$$= \frac{141/680}{231/680}$$

$$= \frac{0.207}{0.340}$$

$$= 0.61 \text{ or } 61\%$$

For Black British males, 46 out of 377 have varying degrees of hypodontia, and 13 have hypodontia with TMA (Table 30). The probability that Black British males have TMA when there are other developmentally missing teeth, i.e., P(TMA/hypodontia), is 28%.

Table 30. Black British male 12.00-19.99 year-olds with TMA and/or hypodontia.

Black British Males	**no TMA**	**TMA**	Total
No Hypodontia	317	14	331
Hypodontia	33	13	46
Total	350	27	**377**

4.6 Hypodontia, TMA, and Third Molar Development

The fourth null hypothesis is that hypodontia or TMA do not affect the timing of dental development. To address this hypothesis with regard to hypodontia, an analysis of the timing of third molar development in subjects with no hypodontia, i.e. all permanent teeth present apart from third molars which may or may not be present, is first presented followed by analyses concerning TMA and Complete Dentitions.

Subjects with a dentition status score of 1, meaning a complete dentition including all third molars, or 2, meaning all teeth present apart from one or more missing third molars, were selected from the whole sample. There were 2,424 subjects in this sub sample, representing 1,293 White British and 1,131 Black British with no hypodontia (Table 31).

Table 31. Ethnicity and sex distribution of sub sample with no hypodontia

	Male	**Female**	Total
White British	653	640	1,293
Black British	562	569	1,131
Total	1,215	1,209	2,424

The results are shown in Tables 32 and 33 and, again, a highly significant ethnic difference is seen in males and females for each TDS, apart from Stage A for which there are limited sample numbers, the LL8 Stage H in males, and UL8 Stage F in females, with TDSs of third molars in the Black British group being seen at a younger age compared to the White British group. For Stages A-H, in males and females, the Bonferroni correction was used to adjust for multiple testing, giving a p value of 0.0016 to denote statistical significance. These findings support the evidence for an ethnic difference per se rather than increased prevalence of hypodontia in the White British group accounting for it.

Table 32. Results for Third Molars Stages A-H (censored Stage H) for Males with no hypodontia, i.e. all permanent teeth present apart from third molars which may or may not be present. T tests applied to TDS A-G and Mann Whitney tests to censored data at TDS H.

	Results for third molars Stages A-H for Males with no hypodontia											
	Black British					difference between Means	p value	White British				
TDS	n	Mean (Median)	SD	Min	Max			n	Mean (Median)	SD	Min	Max
UR8A	13	9.06	1.36	6.97	12.35	0.12	0.7856	29	9.18	1.31	6.80	12.36
UR8B	47	9.18	0.92	7.39	11.51	1.36	<0.0001	85	10.54	1.60	8.17	15.25
UR8C	81	10.62	1.48	7.69	14.09	1.39	<0.0001	127	12.01	1.76	8.48	16.90
UR8D	103	12.51	1.52	8.25	16.36	0.97	<0.0001	104	13.48	1.58	7.81	17.98
UR8E	73	13.87	1.40	10.07	17.41	1.07	0.0001	71	14.94	1.75	10.77	19.66
UR8F	57	15.63	1.22	13.09	19.09	1.03	0.0002	58	16.66	1.64	13.15	21.57
UR8G	57	16.88	1.63	12.89	21.27	1.04	0.0003	58	17.92	1.34	14.88	20.49
UR8H	81	18.85 (18.72)	2.11	15.75	21.22	-0.05(0.21)	0.7920	59	18.80 (18.93)	1.92	14.46	20.45
UL8A	11	8.86	0.81	7.73	10.46	0.60	0.1495	29	9.45	1.24	7.41	12.53
UL8B	45	9.19	0.96	7.39	11.51	1.32	<0.0001	74	10.51	1.54	8.17	15.09
UL8C	82	10.63	1.44	8.39	15.68	1.38	<0.0001	126	12.01	1.87	6.85	17.07
UL8D	103	12.53	1.53	8.25	16.36	0.99	<0.0001	103	13.52	1.74	7.81	18.60
UL8E	79	14.01	1.36	11.24	17.41	0.62	0.0125	75	14.63	1.66	10.77	18.92
UL8F	56	15.61	1.26	13.09	19.39	1.14	0.0001	67	16.75	1.71	13.15	21.57
UL8G	53	16.93	1.52	14.13	20.47	0.99	0.0008	56	17.91	1.46	14.46	21.03
UL8H	82	18.24 (18.28)	2.25	12.89	20.44	0.62 (0.69)	0.0110	57	18.86 (18.97)	1.88	16.28	20.45
LL8A	31	8.52	1.04	6.21	10.46	1.18	0.0003	84	9.69	1.63	6.80	15.09
LL8B	59	9.47	1.28	7.58	13.62	1.79	<0.0001	97	11.26	1.80	8.27	16.70
LL8C	107	11.14	1.54	8.36	15.69	1.44	<0.0001	152	12.57	1.70	8.48	16.51
LL8D	73	12.83	1.48	8.25	16.36	1.30	<0.0001	49	14.13	1.64	10.29	17.99
LL8E	80	14.24	1.41	11.37	19.05	1.39	<0.0001	92	15.64	1.94	10.81	21.57
LL8F	58	15.91	1.24	13.09	19.39	1.35	<0.0001	58	17.26	1.60	13.15	20.83
LL8G	52	17.09	1.44	14.21	20.71	1.53	<0.0001	47	18.62	1.16	15.76	20.69
LL8H	76	18.54 (18.56)	2.25	12.89	20.69	0.36 (0.41)	0.2557	57	18.90 (18.97)	1.98	16.28	20.59
LR8A	30	8.49	1.10	6.21	10.73	1.36	0.0002	86	9.85	1.81	6.80	16.68
LR8B	65	9.41	1.22	7.69	13.62	1.73	<0.0001	91	11.15	1.77	8.27	16.70
LR8C	102	11.27	1.43	8.70	15.69	1.35	<0.0001	158	12.62	1.65	8.48	17.68
LR8D	73	12.89	1.67	8.25	16.73	1.39	<0.0001	50	14.28	1.61	10.77	17.99
LR8E	76	14.25	1.33	11.37	17.69	1.41	<0.0001	73	15.66	2.00	10.81	21.57
LR8F	58	15.91	1.30	13.09	19.39	1.18	<0.0001	70	17.09	1.68	13.15	20.83
LR8G	53	16.77	1.55	12.89	20.47	1.64	<0.0001	44	18.41	1.13	15.76	21.94
LR8H	97	18.58 (18.53)	2.01	15.75	20.44	1.23 (1.50)	<0.0001	64	19.81 (20.03)	1.93	16.28	21.92

Table 33. Results for Third Molars Stages A-H (censored Stage H) for Females with no hypodontia, i.e. all permanent teeth present apart from third molars which may or may not be present. T tests applied to TDS A-G and Mann Whitney tests to censored data at TDS H.

	Results for third molars Stages A-H for Females with no hypodontia											
	Black British					difference between Means	p value	White British				
TDS	n	Mean (Median)	SD	Min	Max			n	Mean (Median)	SD	Min	Max
UR8A	16	8.34	1.24	6.84	10.70	0.96	0.0405	41	9.30	1.65	6.86	13.48
UR8B	42	8.90	1.33	6.60	12.22	1.54	<0.0001	54	10.44	1.78	7.23	14.73
UR8C	71	10.42	1.50	7.81	14.94	1.24	<0.0001	114	11.66	1.88	8.18	18.46
UR8D	114	12.50	1.47	9.31	16.29	1.02	<0.0001	113	13.52	1.78	9.85	20.23
UR8E	87	14.08	1.79	10.08	18.31	1.18	<0.0001	115	15.26	2.04	11.66	20.69
UR8F	58	15.69	1.75	11.70	19.59	0.89	0.0040	68	16.58	1.66	13.54	22.28
UR8G	65	17.12	2.16	12.49	21.91	1.56	0.0001	48	18.67	1.84	15.88	22.96
UR8H	81	19.40 (19.70)	2.14	15.10	21.77	0.96 (0.92)	0.0011	67	20.36 (20.62)	1.97	16.40	22.75
UL8A	17	8.40	1.31	6.70	10.70	1.24	0.0076	38	9.64	1.62	7.84	13.40
UL8B	38	8.66	1.04	6.60	12.19	1.61	<0.0001	60	10.27	1.78	6.86	16.04
UL8C	69	10.29	1.35	7.81	13.40	1.57	<0.0001	108	11.86	1.95	8.18	18.36
UL8D	112	12.38	1.45	9.31	16.80	1.14	<0.0001	116	13.52	1.98	9.85	20.23
UL8E	91	14.16	1.68	10.36	18.17	1.08	<0.0001	120	15.23	1.88	11.69	20.69
UL8F	65	15.80	1.88	11.70	19.59	0.68	0.0339	63	16.48	1.71	12.96	21.32
UL8G	58	17.19	2.39	12.49	21.91	1.59	0.0001	58	18.78	1.86	15.88	23.87
UL8H	82	19.25 (19.40)	2.36	10.48	21.77	1.25 (1.32)	0.0001	62	20.47 (20.72)	1.97	16.40	22.75
LL8A	34	7.93	1.01	6.60	10.84	1.85	<0.0001	91	9.78	1.80	6.86	14.34
LL8B	43	8.82	1.06	6.96	12.19	2.23	<0.0001	84	11.05	1.95	7.61	16.04
LL8C	95	10.82	1.44	7.25	14.67	1.85	<0.0001	134	12.66	1.85	8.84	18.36
LL8D	78	12.75	1.52	10.08	17.13	1.76	<0.0001	84	14.51	1.90	10.43	19.09
LL8E	93	14.12	1.75	10.69	18.71	1.61	<0.0001	108	15.73	1.97	10.98	22.28
LL8F	78	16.02	1.78	12.63	21.49	1.44	<0.0001	61	17.46	1.99	13.97	23.87
LL8G	63	17.60	1.85	14.20	21.91	1.26	0.0002	47	18.85	1.52	15.81	22.89
LL8H	78	19.49 (19.78)	2.12	15.10	21.77	1.08 (1.07)	0.0002	62	20.57 (20.85)	2.02	16.40	22.84
LR8A	32	7.96	1.34	6.34	12.42	1.48	<0.0001	77	9.44	1.46	6.86	13.74
LR8B	51	8.83	1.04	6.96	12.19	2.11	<0.0001	89	10.94	1.78	7.61	15.76
LR8C	98	10.90	1.47	7.25	15.04	1.84	<0.0001	122	12.74	1.96	8.76	20.23
LR8D	86	13.03	1.71	10.08	19.01	1.52	<0.0001	94	14.55	1.89	10.43	19.29
LR8E	75	13.93	1.60	10.36	17.75	1.83	<0.0001	101	15.76	1.72	11.70	20.69
LR8F	82	16.07	1.82	12.49	21.93	1.33	0.0001	55	17.41	2.04	12.96	22.96
LR8G	67	17.63	2.03	13.40	21.91	1.29	0.0004	57	18.92	1.93	14.78	23.87
LR8H	76	19.37 (19.72)	2.16	15.10	21.77	1.44 (1.48)	<0.0001	67	20.81 (21.20)	2.04	16.40	23.33

To investigate a possible association between hypodontia and the timing of third molar development, the differences between the mean ages for TDS A-H in subjects with complete dentitions compared to those of the same sex and ethnicity in the whole sample were calculated. For every TDS, except for UR8A, LL8A and LL8B in Black British males, the mean age was less for those with no hypodontia compared to the whole sample which contained subjects with hypodontia of varying severity (Tables 34 and 35). This shows that, in both sexes and both ethnicities, TDSs occur at a younger age in subjects without hypodontia compared to those with hypodontia.

To further investigate the effect of developmentally missing teeth, mean ages for third molar TDSs for those with complete dentitions, hypodontia, and TMA only, were found. The results for males are seen in Tables 36 and 37. Mean ages are greater in the hypodontia and TMA only samples compared to those with complete dentitions. Although numbers are small, the pattern suggests that, as with hypodontia, TDSs are occurring at an older age in subjects with TMA only compared to those with complete dentitions. Numbers of those with TMA only were insufficient to allow meaningful statistical tests for comparison but Figures 39-42 show bar graphs illustrating mean ages for TDSs in males in the three dentition groups and the pattern of older ages in those with hypodontia or TMA alone compared to complete dentitions. Although not shown, results were similar for females.

Table 34. Table to show difference in mean age of Black British subjects for TDS A-H in third molars between whole sample and those with no hypodontia.

	Black British Males					Black British Females				
	Whole Sample		No Hypodontia		Difference between Means	Whole Sample		No hypodontia		Difference between Means
TDS	n	Mean	n	Mean		n	Mean	n	Mean	
UR8A	16	8.97	13	9.06	-0.08	23	8.47	16	8.34	0.13
UR8B	51	9.21	47	9.18	0.03	49	9.10	42	8.90	0.20
UR8C	97	10.65	81	10.62	0.03	96	10.61	71	10.42	0.19
UR8D	124	12.65	103	12.51	0.14	140	12.86	114	12.50	0.36
UR8E	84	14.01	73	13.87	0.15	105	14.22	87	14.08	0.14
UR8F	75	15.91	57	15.63	0.28	76	15.92	58	15.69	0.23
UR8G	74	17.07	57	16.88	0.19	99	17.77	65	17.12	0.65
UR8H	240	20.72	124	20.14	0.58	262	20.73	110	20.27	0.46
UL8A	14	8.99	11	8.86	0.13	27	8.69	17	8.40	0.29
UL8B	51	9.28	45	9.19	0.08	43	9.00	38	8.66	0.34
UL8C	100	10.64	82	10.63	0.01	88	10.57	69	10.29	0.28
UL8D	122	12.69	103	12.53	0.16	134	12.63	112	12.38	0.25
UL8E	90	14.23	79	14.01	0.22	116	14.38	91	14.16	0.22
UL8F	71	15.88	56	15.61	0.26	78	15.88	65	15.80	0.08
UL8G	69	17.05	53	16.93	0.13	96	17.70	58	17.19	0.51
UL8H	263	20.49	127	19.87	0.62	300	20.80	114	20.11	0.69
LL8A	33	8.49	31	8.52	-0.03	46	8.14	34	7.93	0.22
LL8B	66	9.46	59	9.47	-0.01	56	9.20	43	8.82	0.38
LL8C	128	11.21	107	11.14	0.07	116	10.97	95	10.82	0.15
LL8D	82	12.86	73	12.83	0.03	96	12.96	78	12.75	0.21
LL8E	100	14.44	80	14.24	0.20	120	14.26	93	14.12	0.14
LL8F	72	16.05	58	15.91	0.14	102	16.18	78	16.02	0.16
LL8G	77	17.39	52	17.09	0.29	100	18.04	63	17.60	0.45
LL8H	260	20.60	129	20.06	0.54	302	20.93	110	20.40	0.53
LR8A	34	8.63	30	8.49	0.14	47	8.42	32	7.96	0.46
LR8B	73	9.43	65	9.41	0.01	59	8.99	51	8.83	0.16
LR8C	119	11.33	102	11.27	0.06	124	11.06	98	10.90	0.16
LR8D	86	12.97	73	12.89	0.08	104	13.13	86	13.03	0.09
LR8E	92	14.35	76	14.25	0.11	92	14.14	75	13.93	0.22
LR8F	72	16.07	58	15.91	0.16	102	16.09	82	16.07	0.01
LR8G	78	17.16	53	16.77	0.39	110	17.98	67	17.63	0.35
LR8H	238	20.75	121	20.20	0.55	258	20.85	105	20.25	0.60

Table 35. Table to show difference in mean age of White British subjects for TDS A-H in third molars between whole sample and those with no hypodontia.

	White British Males					White British Females				
	Whole Sample		No Hypodontia		Difference between Means	Whole Sample		No hypodontia		Difference between Means
TDS	n	Mean	n	Mean		n	Mean	n	Mean	
UR8A	33	9.41	29	9.18	0.23	49	9.47	41	9.30	0.18
UR8B	114	10.75	85	10.54	0.21	80	10.95	54	10.44	0.50
UR8C	157	12.23	127	12.01	0.22	152	11.96	114	11.66	0.30
UR8D	133	13.70	104	13.48	0.22	153	13.67	113	13.52	0.15
UR8E	106	15.21	71	14.94	0.27	146	15.48	115	15.26	0.22
UR8F	92	16.92	58	16.66	0.25	104	17.07	68	16.58	0.49
UR8G	90	18.16	58	17.92	0.24	89	19.06	48	18.67	0.39
UR8H	353	21.05	143	20.68	0.37	294	21.34	90	21.01	0.33
UL8A	43	9.91	29	9.45	0.46	46	9.87	38	9.64	0.22
UL8B	93	10.57	74	10.51	0.05	83	10.52	60	10.27	0.25
UL8C	162	12.29	126	12.01	0.28	151	12.25	108	11.86	0.39
UL8D	138	13.85	103	13.52	0.33	159	13.74	116	13.52	0.21
UL8E	106	14.88	75	14.63	0.26	155	15.52	120	15.23	0.29
UL8F	101	16.87	67	16.75	0.11	99	17.06	63	16.48	0.57
UL8G	94	18.11	56	17.91	0.19	111	19.21	58	18.78	0.43
UL8H	385	21.14	150	20.73	0.41	308	21.45	86	21.19	0.26
LL8A	107	9.90	84	9.69	0.20	115	9.94	91	9.78	0.16
LL8B	125	11.40	97	11.26	0.14	110	11.08	84	11.05	0.03
LL8C	184	12.83	152	12.57	0.26	180	12.81	134	12.66	0.15
LL8D	67	14.23	49	14.13	0.10	120	14.79	84	14.51	0.28
LL8E	134	15.77	92	15.64	0.13	136	15.98	108	15.73	0.26
LL8F	87	17.42	58	17.26	0.16	95	17.89	61	17.46	0.43
LL8G	80	18.80	47	18.62	0.18	114	19.83	47	18.85	0.98
LL8H	373	21.24	136	20.80	0.44	316	21.48	85	21.27	0.21
LR8A	109	10.04	86	9.85	0.19	96	9.71	77	9.44	0.27
LR8B	123	11.35	91	11.15	0.20	119	11.06	89	10.94	0.12
LR8C	188	12.80	158	12.62	0.18	167	12.96	122	12.74	0.22
LR8D	76	14.39	50	14.28	0.10	124	14.63	94	14.55	0.08
LR8E	105	15.96	73	15.66	0.31	127	16.00	101	15.76	0.24
LR8F	103	17.31	70	17.09	0.22	92	17.84	55	17.41	0.43
LR8G	81	18.74	44	18.41	0.33	116	19.59	57	18.92	0.67
LR8H	344	21.17	140	20.72	0.45	276	21.58	75	21.23	0.35

Table 36. Mean age at third molar TDS A-H in White British males with three different dentition statuses.

	White British Males					
	Complete Dentitions		Hypodontia (and/or TMA)		TMA only	
TDS	n	Mean	n	Mean	n	Mean
UR8A	14	9.08	16	9.65	15	9.27
UR8B	69	10.34	37	11.70	16	11.42
UR8C	112	11.86	41	13.17	15	13.09
UR8D	94	13.39	32	14.30	10	14.30
UR8E	68	14.87	31	15.74	3	16.42
UR8F	56	16.60	24	16.99	2	18.35
UR8G	56	17.90	18	18.10	2	18.67
UR8H	140	20.68	22	20.20	3	20.78
UL8A	22	9.43	17	10.71	7	9.53
UL8B	54	10.36	31	11.09	20	10.93
UL8C	114	11.87	44	13.20	12	13.36
UL8D	91	13.33	37	15.04	12	14.99
UL8E	71	14.62	28	15.41	4	14.77
UL8F	62	16.60	28	17.09	5	18.65
UL8G	53	17.83	22	18.17	3	19.46
UL8H	142	20.79	27	20.02	8	19.76
LL8A	40	9.71	58	10.10	44	9.68
LL8B	79	11.13	36	11.98	18	11.81
LL8C	142	12.51	39	14.00	10	13.46
LL8D	43	14.05	20	14.65	6	14.71
LL8E	89	15.59	36	16.29	3	17.09
LL8F	55	17.18	16	17.56	3	18.69
LL8G	45	18.65	12	18.23	2	18.08
LL8H	132	20.80	17	19.94	4	20.71
LR8A	46	9.95	52	9.99	40	9.74
LR8B	73	10.93	39	12.09	18	12.02
LR8C	146	12.55	37	13.83	12	13.44
LR8D	44	14.08	28	15.01	6	15.80
LR8E	71	15.58	28	16.86	2	18.27
LR8F	64	16.98	21	17.40	6	18.24
LR8G	44	18.41	10	18.63	0	
LR8H	138	20.73	15	19.83	2	20.13

Table 37. Mean age at third molar TDS A-H in Black British males with three different dentition statuses

	Black British Males					
	Complete Dentitions		Hypodontia (and/or TMA)		TMA only	
TDS	n	Mean	n	Mean	n	Mean
UR8A	9	8.78	5	9.80	4	9.69
UR8B	44	9.13	5	10.03	3	9.88
UR8C	80	10.61	8	11.42	1	11.47
UR8D	101	12.47	17	13.33	2	14.79
UR8E	70	13.91	6	13.68	3	12.75
UR8F	57	15.63	10	17.09	0	
UR8G	56	16.84	3	18.64	1	19.05
UR8H	124	20.14	6	19.91	0	
UL8A	11	8.86	2	10.44	0	
UL8B	42	9.18	6	9.65	3	9.38
UL8C	77	10.47	12	12.04	5	12.99
UL8D	100	12.57	19	12.99	3	11.22
UL8E	77	14.01	6	16.34	2	14.09
UL8F	54	15.56	9	16.86	2	17.12
UL8G	52	16.89	3	16.95	1	19.05
UL8H	127	19.87	8	20.08	0	
LL8A	20	8.79	11	8.02	11	8.02
LL8B	51	9.52	13	9.29	8	9.16
LL8C	102	11.13	18	11.61	5	11.19
LL8D	70	12.86	11	12.52	3	12.07
LL8E	77	14.18	12	15.41	3	15.89
LL8F	57	15.85	8	16.83	1	19.39
LL8G	51	17.08	7	18.23	1	17.99
LL8H	129	20.06	8	20.25	0	
LR8A	18	8.84	13	8.18	12	7.97
LR8B	57	9.42	14	9.32	8	9.38
LR8C	98	11.26	13	11.93	4	11.50
LR8D	70	12.92	13	12.73	3	12.07
LR8E	75	14.26	7	14.11	1	13.15
LR8F	56	15.81	8	17.15	2	18.69
LR8G	53	16.77	6	18.06	0	
LR8H	121	20.20	8	20.40	0	

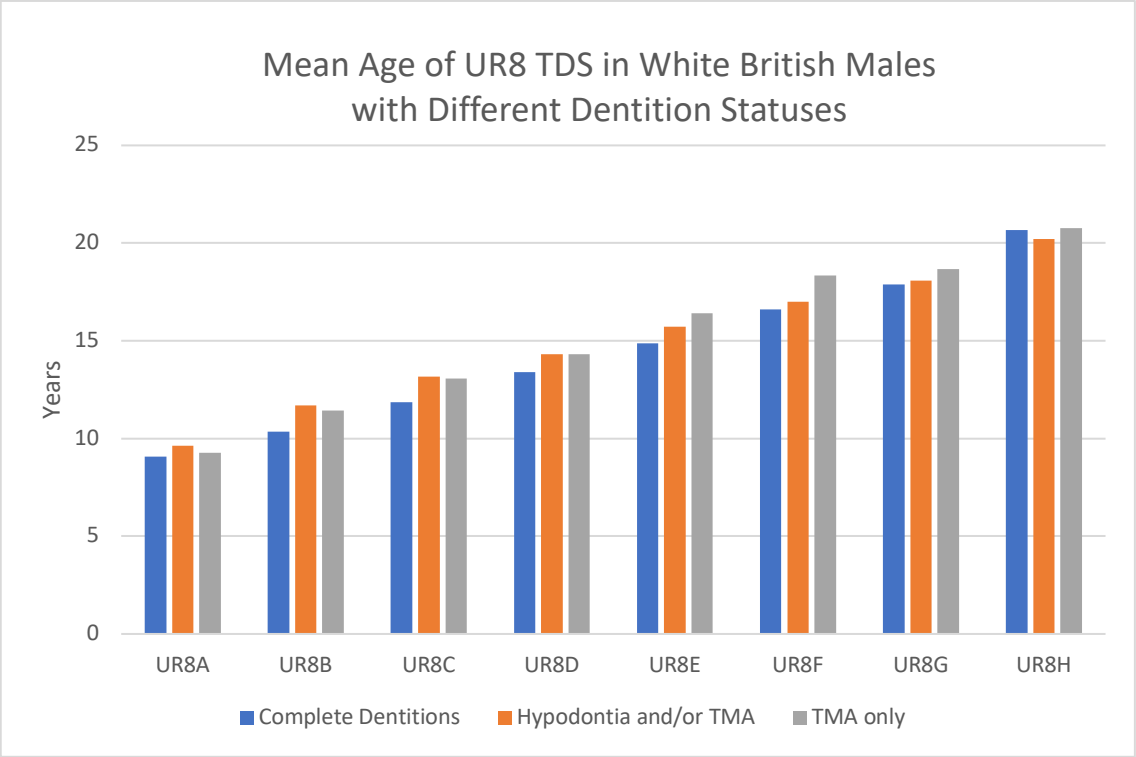


Figure 39. Bar Graph to compare Mean Age at Assessment of UR8 TDSs in White British Males with Complete Dentitions, Hypodontia, and TMA only.

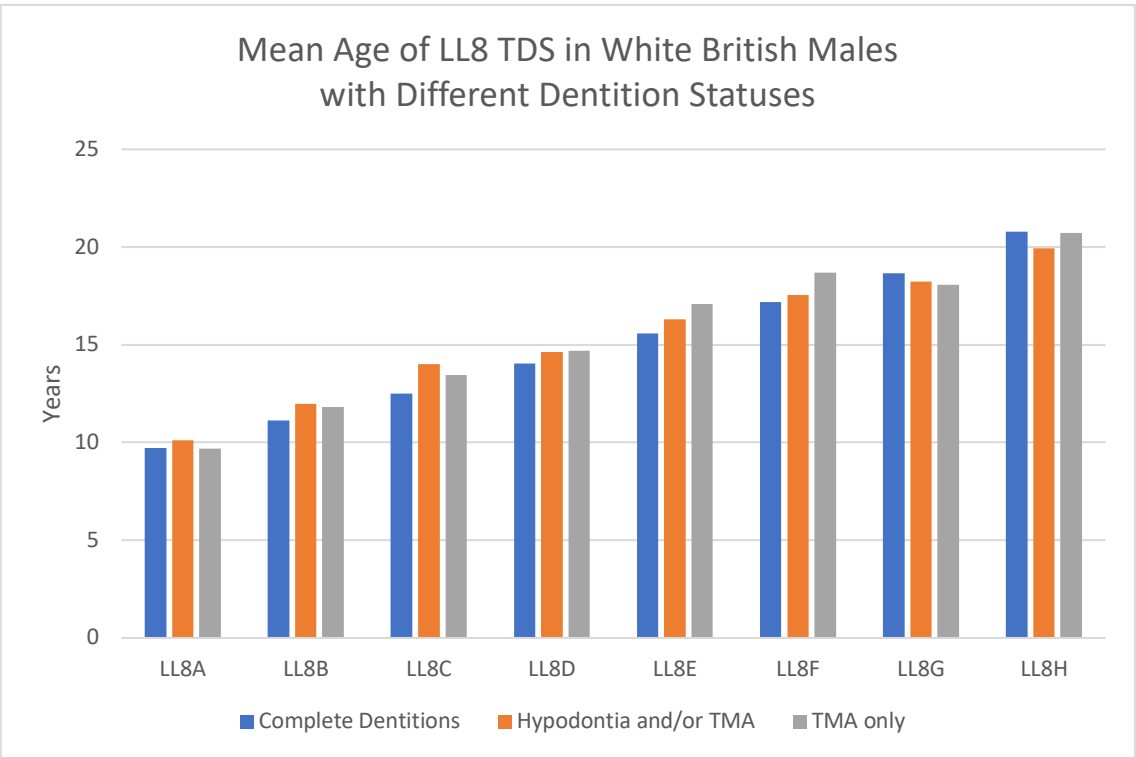


Figure 40. Bar Graph to compare Mean Age at Assessment of LL8 TDSs in White British Males with Complete Dentitions, Hypodontia, and TMA only.

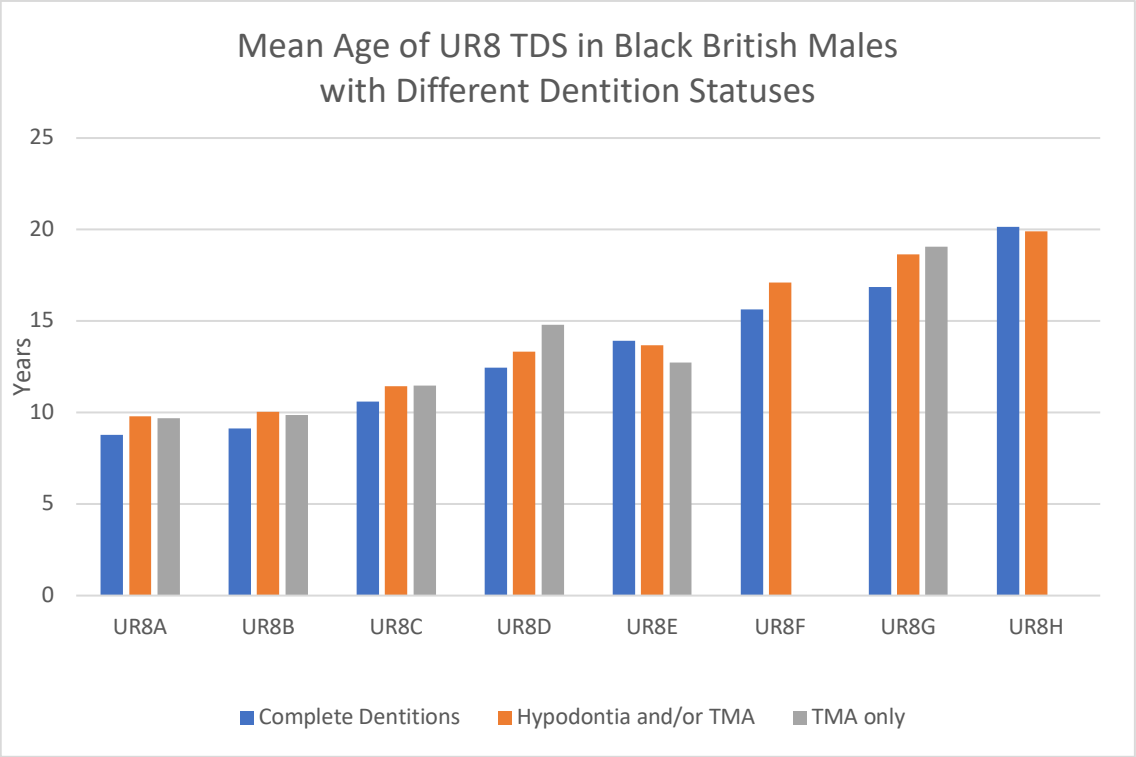


Figure 41. Bar Graph to compare Mean Age at Assessment of UR8 TDSs in Black British Males with Complete Dentitions, Hypodontia, and TMA only.

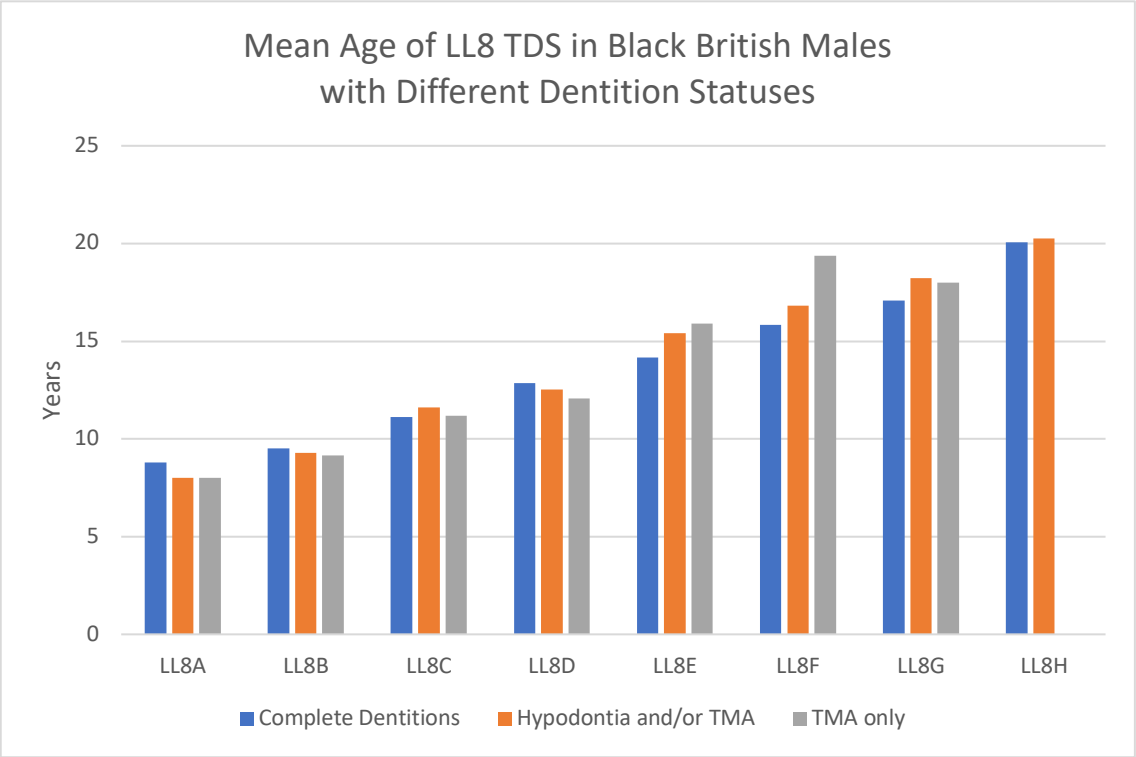


Figure 42. Bar Graph to compare Mean Age at Assessment of LL8 TDSs in Black British Males with Complete Dentitions, Hypodontia, and TMA only.

Finally, with regard to dentition status and third molar development, a comparison was made between the two ethnic groups in subjects who all had complete dentitions. The results from this sub sample (Table 38) are shown in Tables 39 and 40 and confirm the highly significant ethnic difference with a p value of <0.0016 to incorporate the Bonferroni correction, in both males and females at all stages of third molar development and also the wide age ranges at each TDS.

Table 38. Sub sample of subjects with Complete Dentitions.

	Males	Females	**Total**
White British	653	640	**1,293**
Black British	562	569	**1,131**
Total	**1,215**	**1,209**	**2,424**

The risk of overestimation of age of both males and females of Black ethnicity at the 18-year-old threshold if White British reference data were to be used in DAE is clear from these third molar results. It has also been demonstrated that third molar TDSs occur at older ages, in both sexes and ethnicities, when hypodontia, hypodontia with or without TMA, and TMA alone, is present. These findings also have consequences for DAE.

Table 39. Results for Third Molars Stages A-H (censored Stage H) for Males with Complete Dentitions, i.e. all permanent teeth present apart including third molars.

	Comparison of Third Molars Stages A-H in Males with Complete Dentitions											
	Black British					Difference between Means/ Medians	**p value** T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max			n	Mean Median	SD	Min	Max
UR8A	9	8.78	1.04	6.97	10.46	0.30	0.2427	14	9.08	0.98	7.87	11.35
UR8B	44	9.13	0.92	7.39	11.51	1.21	<0.0001	69	10.34	1.39	8.17	13.43
UR8C	80	10.61	1.49	7.69	14.09	1.26	<0.0001	112	11.86	1.67	8.48	16.90
UR8D	101	12.47	1.50	8.25	16.36	0.93	<0.0001	94	13.39	1.46	9.59	17.98
UR8E	70	13.91	1.33	11.24	17.41	0.96	0.0002	68	14.87	1.72	10.77	19.66
UR8F	57	15.63	1.22	13.09	19.09	0.97	0.0002	56	16.60	1.63	13.15	21.57
UR8G	56	16.84	1.62	12.89	21.27	1.05	0.0001	56	17.90	1.35	14.88	20.49
UR8H	124	20.14	2.11	15.75	23.90	0.53	0.0161	140	20.68	1.92	14.46	23.95
	81	18.72		15.75	21.22	0.20	0.7920	67	18.93		14.46	20.45
UL8A	11	8.86	0.81	7.73	10.46	0.57	0.0792	22	9.43	1.17	7.87	11.98
UL8B	42	9.18	0.96	7.39	11.51	1.18	<0.0001	54	10.36	1.42	8.17	13.54
UL8C	77	10.47	1.25	8.39	13.97	1.39	<0.0001	114	11.87	1.71	8.48	17.07
UL8D	100	12.57	1.50	8.25	16.36	0.76	0.0003	91	13.33	1.49	9.59	17.98
UL8E	77	14.01	1.36	11.24	17.41	0.61	0.0083	71	14.62	1.70	10.77	18.92
UL8F	54	15.56	1.17	13.09	18.21	1.04	0.0001	62	16.60	1.62	13.15	21.57
UL8G	52	16.89	1.50	14.13	20.47	0.94	0.0007	53	17.83	1.43	14.46	20.49
UL8H	127	19.87	2.25	12.89	23.89	0.91	0.0002	142	20.79	1.85	16.28	23.95
	72	18.28		12.89	20.44	0.69	0.0110	57	18.97		16.28	20.45
LL8A	20	8.79	0.92	6.97	10.46	0.92	0.0034	40	9.71	1.31	7.87	12.59
LL8B	51	9.52	1.31	7.69	13.62	1.62	<0.0001	79	11.13	1.67	8.45	16.70
LL8C	102	11.13	1.52	8.36	15.69	1.38	<0.0001	142	12.51	1.69	8.48	16.51
LL8D	70	12.86	1.44	8.25	16.36	1.19	0.0001	43	14.05	1.68	10.29	17.99
LL8E	77	14.18	1.31	11.37	17.69	1.41	<0.0001	89	15.59	1.95	10.81	21.57
LL8F	57	15.85	1.16	13.09	18.48	1.33	<0.0001	55	17.18	1.55	13.15	20.49
LL8G	51	17.08	1.45	14.21	20.71	1.57	<0.0001	45	18.65	1.10	15.76	20.69
LL8H	129	20.06	2.25	12.89	23.90	0.74	0.0023	132	20.80	1.95	16.28	23.95
	76	18.55		12.89	20.69	0.41	0.2557	57	18.97		16.28	20.59
LR8A	18	8.84	1.01	6.97	10.73	1.11	0.0030	46	9.95	1.52	7.87	13.69
LR8B	57	9.42	1.27	7.69	13.62	1.52	<0.0001	73	10.93	1.62	8.51	16.70
LR8C	98	11.26	1.40	8.70	15.69	1.29	<0.0001	146	12.55	1.62	8.48	17.68
LR8D	70	12.92	1.64	8.25	16.73	1.15	0.0001	44	14.08	1.51	10.77	17.99
LR8E	75	14.26	1.33	11.37	17.69	1.32	<0.0001	71	15.58	1.97	10.81	21.57
LR8F	56	15.81	1.20	13.09	18.48	1.17	<0.0001	64	16.98	1.62	13.15	20.49
LR8G	53	16.77	1.55	12.89	20.47	1.64	<0.0001	44	18.41	1.13	15.76	21.94
LR8H	121	20.20	2.01	15.75	23.90	0.53	0.0148	138	20.73	1.91	16.28	23.95
	64	18.53		15.75	20.44	1.50	<0.0001	97	20.03		16.28	21.92

Table 40. Results for Third Molars Stages A-H (censored Stage H) for Females with Complete Dentitions, i.e. all permanent teeth present apart including third molars.

	Comparison of Third Molars Stages A-H in Females with Complete Dentitions											
	Black British					Difference between Means	**p value** T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max			n	Mean Median	SD	Min	Max
UR8A	13	8.55	1.27	6.97	10.70	0.90	0.0394	31	9.45	1.60	6.86	13.18
UR8B	38	8.86	1.36	6.60	12.22	1.53	<0.0001	46	10.38	1.84	7.23	14.73
UR8C	66	10.26	1.37	7.81	14.94	1.29	<0.0001	99	11.55	1.74	8.18	17.22
UR8D	109	12.46	1.44	9.31	16.29	0.92	<0.0001	104	13.38	1.70	9.85	20.23
UR8E	85	14.06	1.80	10.08	18.31	1.07	0.0001	107	15.13	1.97	11.66	20.69
UR8F	56	15.63	1.75	11.70	19.59	0.90	0.0019	66	16.54	1.62	13.54	22.28
UR8G	64	17.12	2.18	12.49	21.91	1.55	0.0001	46	18.67	1.87	15.88	22.96
UR8H	109	20.27	2.15	15.10	23.91	0.71	0.0095	84	20.99	1.98	16.40	23.85
	81	19.69			21.77	0.93	0.0011	67	20.62			22.75
UL8A	15	8.57	1.30	6.97	10.70	1.09	0.0109	30	9.65	1.51	7.84	13.18
UL8B	35	8.64	1.09	6.60	12.19	1.50	<0.0001	50	10.14	1.78	6.86	16.04
UL8C	64	10.15	1.26	7.81	13.40	1.64	<0.0001	94	11.79	1.90	8.18	18.36
UL8D	109	12.38	1.46	9.31	16.80	0.94	<0.0001	104	13.33	1.82	9.85	20.23
UL8E	89	14.15	1.70	10.36	18.17	0.98	0.0001	114	15.13	1.79	11.69	20.69
UL8F	63	15.76	1.89	11.70	19.59	0.72	0.0131	63	16.48	1.71	12.96	21.32
UL8G	55	17.14	2.43	12.49	21.91	1.52	0.0002	53	18.66	1.78	15.88	22.96
UL8H	111	20.19	2.20	15.10	23.91	0.95	0.0013	80	21.14	2.00	16.40	23.85
	82	19.40		15.10	21.77	1.32	0.0001	62	20.72		16.40	22.75
LL8A	17	7.99	0.95	6.60	10.47	1.84	0.0001	54	9.84	1.89	6.86	14.34
LL8B	38	8.93	1.06	6.96	12.19	2.11	<0.0001	72	11.04	1.98	7.61	16.04
LL8C	92	10.80	1.45	7.25	14.67	1.72	<0.0001	124	12.51	1.78	8.84	18.36
LL8D	75	12.66	1.42	10.08	16.33	1.69	<0.0001	73	14.36	1.91	10.43	19.09
LL8E	89	14.08	1.77	10.69	18.71	1.64	<0.0001	103	15.72	1.96	10.98	22.28
LL8F	78	16.02	1.78	12.63	21.49	1.40	<0.0001	56	17.42	1.83	14.38	22.96
LL8G	61	17.56	1.86	14.20	21.91	1.24	0.0002	43	18.80	1.53	15.81	22.89
LL8H	108	20.42	2.13	15.10	23.91	0.83	0.0038	81	21.25	2.03	16.40	23.85
	78	19.78		15.10	21.77	1.08	0.0002	62	20.85		16.40	22.84
LR8A	13	7.88	1.00	6.60	10.47	1.68	0.0003	50	9.56	1.57	6.86	13.74
LR8B	44	8.88	1.02	6.96	12.19	2.12	<0.0001	79	11.01	1.78	7.61	15.76
LR8C	96	10.90	1.49	7.25	15.04	1.72	<0.0001	112	12.62	1.89	8.76	20.23
LR8D	82	12.93	1.66	10.08	19.01	1.43	<0.0001	84	14.35	1.85	10.43	19.29
LR8E	72	13.86	1.60	10.36	17.75	1.88	<0.0001	96	15.75	1.69	11.90	20.69
LR8F	79	15.95	1.70	12.49	19.59	1.51	<0.0001	53	17.46	2.02	12.96	22.96
LR8G	66	17.62	2.04	13.40	21.91	1.30	0.0002	53	18.91	1.84	14.78	23.34
LR8H	103	20.27	2.18	15.10	23.91	0.94	0.0021	72	21.21	2.04	16.40	23.85
	76	19.72		15.10	21.77	1.48	<0.0001	62	21.20		16.40	23.33

4.7 Results for Left-sided Teeth

The results for third molar development pose significant difficulties if DAE is to be used to establish the 18-year-old threshold and its attendant life-changing consequences. However, there are other different yet important reasons for DAE when, contrary to methods employed for the 18-year-old or other age thresholds, an atlas system is generally preferred, e.g. for identifying individuals in family groups in a mass disaster scenario. Therefore, the development of teeth on the left side was compared to allow possible ethnic differences in the timing of dental development as a whole to be evaluated and also be relevant to those under the age of 16. Lastly, the possibility of compiling separate atlas illustrations for each sex and ethnic group is presented.

Summary Data for Left-sided Teeth

The summary data for the upper and lower left incisors, canines, premolars and first and second molars are shown in Tables 41 – 48.

Tables 41 and 42 show the results, for males and females respectively, for the upper left central and lateral incisors, canine and first premolar with t tests for Stages A-G and Mann-Whitney tests for Stage H data censored at the maximum age within 3SD of the mean age for Stage G. A highly significant ethnic difference is seen at Stage G ($p<0.004$) and H ($p<0.0001$) in all these teeth in females with the Black British ahead of the White British. Based on the mean ages, in Black British females compared to White British females, Stage H occurs in the UL1 approximately 9 months ahead, 7 months ahead for the UL2, 17 months ahead for the UL3 and 26 ahead months for the UL4. In males, however, Black British are ahead of the White British for Stage H of the UL1 ($p<0.0001$), by approximately 10 months, but for the UL2, UL3 and UL4, the White British are ahead at Stage H. In this apparent reversal, the difference is significant for the UL2 and UL4 ($p<0.01$) with White British males ahead by 6 months and 2 months respectively. No ethnic difference was seen in males for the UL3. All these teeth start to form in infancy and their early stages are not represented in this sample as the lower limit is six years of age. The middle stages are poorly represented as the majority of the sample show these teeth in their final stages. Meaningful comparisons are not

possible for the earlier stages, and even the ethnic difference at Stage H should perhaps be viewed with some scepticism unless the difference at Stage G is significant.

The lower left central and lateral incisors, canine and first premolar are similarly shown in Tables 43 and 44. Lower incisors and the lower first premolar tend to develop ahead of their counterparts in the maxilla and this means that there are even fewer of the early stages represented in the sample than for the maxillary counterparts. In males, White British appear to be ahead at Stage H for the LL1 and LL2 but the difference is not significant at Stage G so the differences at Stage H are not very substantiated. LL3 in Black British develops significantly ahead of White British for Stages E-G but the difference is not significant at Stage H. For the LL4, there is an ethnic difference at Stages F and G, with Black British males ahead by 4 months at Stage H. In females, White British are significantly ahead at Stage H of LL2 but the difference at Stage G is not significantly different. Black British females are ahead of White British females at Stages G and H of the lower first premolar, LL4 ($p<0.04$), as is so with the LL3 at Stage G ($p<0.02$) but not at Stage H.

Tables 45 and 46 show results for the upper left second premolar (UL5), first molar (UL6), and second molar (UL7) for males and females respectively. As with the more anterior teeth, many of the early stages occur before the age of six and are therefore not represented in this sample. At the later stages there are difficulties in interpreting the data because even if an ethnic difference is significant at Stage H it is not always so at Stage G. However, the males and females of the Black British group appear to be significantly ahead of the White British group with respect to the UL5. Ethnic differences are generally unclear for the UL6 and UL7, although White British females are ahead of Black British at Stage H of the UL6 ($p<0.0001$).

Results for the lower left second premolar (LL5), first molar (LL6), and second molar (LL7) (Tables 47 and 48) show that the Black British males and females are significantly ahead of White British in the development of LL5 at Stages E, F, G and H in males ($p<0.03$) and F, G and H in females ($p<0.0006$). This significant difference is also present for the LL7 for Stages F, G and H in males ($p<0.005$), and Stages E, F, G and H in females ($p<0.01$). For the LL6, in both males and females, the only significant difference is at Stage H ($p<0.0001$) with the Black British being ahead of their White British counterparts.

Table 41. Summary Data for UL1, UL2, UL3 and UL4 in Males

	Results for UL1, UL2, UL3 & UL4 Stages A-H for Males - and Censored Stage H (blue)											
	Black British					difference between Means	p value T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max			n	Mean Median	SD	Min	Max
UL1A	0						N/A	1	9.67		9.67	9.67
UL1B	0						N/A	0				
UL1C	0					6.04	N/A	1	6.04		6.04	6.04
UL1D	4	7.47	1.29	6.16	8.99	-0.55	0.2296	25	6.92	0.76	6.05	9.39
UL1E	5	6.74	0.32	6.39	7.22	0.32	0.3195	46	7.06	0.71	6.01	9.48
UL1F	21	7.77	0.65	6.85	9.09	0.07	0.7120	106	7.84	0.84	6.03	10.34
UL1G	44	9.06	1.76	6.76	17.61	0.68	0.0530	86	9.74	1.92	6.81	16.22
UL1H	582	15.39	4.06	7.39	23.98	1.14	0.0005	952	16.13	4.00	7.58	23.92
	255	11.81			14.35	0.81	<0.0001	435	12.62			15.49
UL2A	0					0.00	N/A	0				
UL2B	0					10.48	N/A	1	10.48	.	10.48	10.48
UL2C	3	6.37	0.28	6.16	6.69	-0.06	0.7604	6	6.31	0.29	6.04	6.66
UL2D	9	7.37	1.17	6.39	9.50	-0.30	0.3034	49	7.07	0.73	6.08	9.48
UL2E	12	7.72	0.62	6.97	9.22	-0.22	0.3628	54	7.50	0.77	6.03	9.89
UL2F	44	8.45	1.18	6.76	13.98	0.12	0.5256	106	8.57	0.94	6.74	10.88
UL2G	44	9.45	1.20	7.39	13.05	0.32	0.1533	87	9.77	1.20	7.15	15.09
UL2H	547	15.92	3.79	8.25	23.98	0.30	0.0011	813	16.61	3.82	9.45	23.95
	138	11.87			13.05	-0.52	<0.0001	198	11.35			13.35
UL3A	0					0.00	N/A	0				
UL3B	0					0.00	N/A	0				
UL3C	2	6.92	1.08	6.16	7.69	-0.23	0.6935	18	6.69	0.76	6.04	9.39
UL3D	27	7.42	0.92	6.21	9.22	0.06	0.7501	154	7.48	0.86	6.01	10.02
UL3E	39	8.28	0.73	6.76	9.78	0.18	0.2540	98	8.46	0.86	6.59	10.34
UL3F	132	9.76	1.10	7.39	12.27	0.72	<0.0001	238	10.48	1.28	6.81	15.09
UL3G	93	12.06	1.72	8.25	18.73	0.52	0.0198	122	12.57	1.49	9.25	16.49
UL3H	450	17.29	3.36	9.45	23.98	-0.73	0.0100	777	17.79	3.22	9.58	23.95
	229	14.68			17.21	-0.04	0.4966	298	14.64			16.49
UL4A	0					0.00	N/A	0				
UL4B	0					0.00	N/A	0				
UL4C	3	6.55	0.36	6.16	6.89	0.20	0.5232	27	6.76	0.53	6.04	7.74
UL4D	29	7.51	0.78	6.21	9.11	0.00	0.9797	114	7.51	0.88	6.01	10.12
UL4E	39	8.60	0.76	7.20	9.94	0.00	0.9873	78	8.60	1.07	6.59	11.50
UL4F	66	9.81	1.48	7.46	17.67	0.54	0.0208	117	10.35	1.51	7.58	15.07
UL4G	87	11.26	1.56	8.25	15.85	0.28	0.1808	135	11.53	1.47	8.40	15.20
UL4H	461	17.50	3.44	9.40	23.99	0.37	0.0634	743	17.87	3.35	9.58	23.95
	171	14.09			15.85	-0.16	0.0131	183	13.93			15.19

Table 42. Summary Data for UL1, UL2, UL3 and UL4 in Females

	Results for UL1, UL2, UL3 & UL4 Stages A-H for Females - and Censored Stage H (blue)											
	Black British					difference between Means	p value T tests	White British				
TDS	n	Mean Median	SD	Min	Max		M-W tests	n	Mean Median	SD	Min	Max
UL1A	0					0.00	N/A	0				
UL1B	0					0.00	N/A	0				
UL1C	0					0.00	N/A	0				
UL1D	1	6.89		6.89	6.89	0.01	N/A	12	6.90	0.91	6.10	9.19
UL1E	2	7.24	0.78	6.69	7.79	-0.38	0.3917	32	6.86	0.59	6.02	8.28
UL1F	21	7.41	0.55	6.34	8.22	-0.01	0.9386	88	7.40	0.71	6.03	9.59
UL1G	41	8.16	1.00	6.60	11.69	0.64	0.0044	88	8.80	1.24	6.81	13.74
UL1H	631	15.34	4.09	6.97	23.94	0.14	0.5112	942	15.48	3.98	6.36	24.00
	125	10.11			11.50	0.78	<0.0001	252	10.89			12.53
UL2A	0					0.00	N/A	0				
UL2B	0					0.00	N/A	0				
UL2C	0					6.75	N/A	1	6.75		6.75	6.75
UL2D	3	6.78	0.30	6.45	7.01	0.19	0.6175	18	6.98	0.64	6.02	8.28
UL2E	9	7.36	0.49	6.34	7.97	-0.36	0.0540	45	7.00	0.50	6.02	8.16
UL2F	36	7.88	0.69	6.70	9.67	0.22	0.1824	98	8.10	0.88	6.22	10.54
UL2G	46	8.89	1.08	6.60	11.73	0.55	0.0038	86	9.44	1.00	7.29	13.09
UL2H	614	15.66	3.97	7.26	23.94	0.25	0.2312	834	15.91	3.86	8.04	24.00
	112	10.48			11.71	0.60	<0.0001	182	11.08			12.44
UL3A	0					0.00	1.4400	0				
UL3B	0					0.00	N/A	0				
UL3C	1	6.69		6.69	6.69	0.51	N/A	12	7.19	0.96	6.25	9.19
UL3D	17	7.31	0.90	6.08	9.11	-0.19	0.3571	91	7.12	0.76	6.02	9.87
UL3E	33	7.68	0.57	6.70	9.03	0.02	0.8783	99	7.71	0.86	6.22	10.44
UL3F	103	9.01	1.12	6.60	11.82	0.48	0.0003	201	9.49	1.08	7.09	12.10
UL3G	66	10.64	1.26	7.26	13.95	0.79	0.0003	130	11.43	1.50	8.47	16.96
UL3H	557	16.62	3.55	9.97	23.94	0.29	0.1260	800	16.91	3.42	6.36	24.00
	149	12.40			13.94	1.44	<0.0001	348	13.84			15.93
UL4A	0					0.00	N/A	0				
UL4B	1	15.00		15.00	15.00	-8.27	N/A	1	6.73		6.73	6.73
UL4C	4	7.77	2.74	6.08	11.85	-0.98	0.1774	19	6.79	0.81	6.02	9.19
UL4D	27	7.68	1.11	6.34	11.85	-0.28	0.1975	91	7.40	0.95	6.02	10.54
UL4E	41	7.96	0.86	6.45	11.13	0.23	0.1706	91	8.19	0.92	6.27	10.03
UL4F	56	9.23	1.18	6.89	11.87	0.32	0.1103	112	9.55	1.24	7.21	14.47
UL4G	79	10.45	1.31	7.54	13.82	0.70	0.0044	142	11.15	1.91	7.68	19.59
UL4H	560	17.33	3.69	9.66	23.94	0.10	0.6148	749	17.43	3.50	9.33	24.00
	112	12.40			13.80	2.20	<0.0001	357	14.60			16.89

Table 43. Summary Data for LL1, LL2, LL3 and LL4 in Males

	Results for LL1, LL2, LL3 & LL4 Stages A-H for Males - and Censored Stage H (blue)											
	Black British					difference between Means	p value T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max			n	Mean Median	SD	Min	Max
LL1A	0					0.00	N/A	0				
LL1B	0					0.00	N/A	0				
LL1C	0					0.00	N/A	0				
LL1D	1	6.16	.	6.16	6.16	-0.08	N/A	2	6.08	0.05	6.04	6.12
LL1E	0					7.22	N/A	2	7.22	0.35	6.97	7.46
LL1F	3	6.87	0.47	6.39	7.33	0.10	0.8203	38	6.96	0.72	6.05	9.39
LL1G	21	7.85	1.45	6.21	11.64	-0.36	0.1108	87	7.49	0.75	6.01	9.48
LL1H	621	15.01	4.33	6.76	23.98	0.30	0.1699	1092	15.31	4.40	6.77	23.95
	167	9.85			11.63	-1.21	<0.0001	110	8.64			9.46
LL2A	0					0.00	N/A	0				
LL2B	0					0.00	N/A	0				
LL2C	0					6.97	N/A	1	6.97	.	6.97	6.97
LL2D	2	7.10	1.33	6.16	8.05	-0.42	0.5627	5	6.68	0.62	6.04	7.54
LL2E	2	6.64	0.35	6.39	6.89	0.14	0.7626	28	6.78	0.65	6.05	9.39
LL2F	11	7.17	0.56	6.21	8.00	0.15	0.4848	75	7.33	0.70	6.01	8.86
LL2G	37	8.81	1.44	6.54	13.05	-0.19	0.3980	106	8.61	1.09	6.59	13.93
LL2H	618	15.34	4.15	7.10	23.98	0.58	0.0057	1059	15.92	4.10	6.80	23.95
	204	10.70			13.05	-0.06	0.0056	217	10.64			11.88
LL3A	0					0.00	N/A	0				
LL3B	0					0.00	N/A	0				
LL3C	7	7.07	0.60	6.16	8.03	-0.25	0.3304	17	6.81	0.56	6.03	8.04
LL3D	29	7.72	0.94	6.21	9.22	-0.43	0.0291	92	7.29	0.90	6.04	11.50
LL3E	31	8.46	1.00	6.97	11.13	-0.50	0.0092	128	7.96	0.93	6.01	10.29
LL3F	114	9.56	1.07	7.39	12.19	0.56	0.0001	253	10.12	1.32	6.81	15.09
LL3G	101	11.80	1.52	8.25	16.36	0.68	0.0004	162	12.47	1.45	8.48	16.21
LL3H	472	17.16	3.35	9.71	23.98	0.50	0.0080	832	17.66	3.21	9.58	23.95
	215	14.26			16.34	0.19	0.6659	296	14.45			16.21
LL4A	0					0.00	N/A	0				
LL4B	0					0.00	N/A	0				
LL4C	6	6.84	0.71	6.16	8.05	-0.14	0.5678	22	6.69	0.48	6.04	7.69
LL4D	41	7.75	0.88	6.21	9.67	-0.26	0.0993	146	7.49	0.89	6.01	10.29
LL4E	55	8.67	0.68	7.39	10.44	-0.14	0.3396	130	8.53	0.97	6.43	11.50
LL4F	85	10.19	1.16	7.81	13.64	0.50	0.0087	205	10.68	1.56	8.02	18.54
LL4G	79	11.59	1.52	8.25	15.85	0.57	0.0041	130	12.16	1.28	8.48	16.49
LL4H	539	17.17	3.50	9.40	23.99	0.45	0.0147	861	17.63	3.30	9.58	23.95
	217	13.89			15.85	0.36	0.0031	304	14.25			15.98

Table 44. Summary Data for LL1, LL2, LL3 and LL4 in Females

	Results for LL1, LL2, LL3 & LL4 Stages A-H for Females - and Censored Stage H (blue)											
	Black British					difference between Means	p value T tests	White British				
TDS	n	Mean Median	SD	Min	Max		M-W tests	n	Mean Median	SD	Min	Max
LL1A	0					0.00	N/A	0				
LL1B	0					0.00	N/A	0				
LL1C	0					0.00	N/A	0				
LL1D	0					6.63	N/A	1	6.63	.	6.63	6.63
LL1E	0					6.38	N/A	5	6.38	0.37	6.02	6.88
LL1F	2	6.17	0.13	6.08	6.26	0.52	0.0287	23	6.69	0.31	6.02	7.27
LL1G	12	7.37	0.63	6.45	8.45	-0.07	0.7628	76	7.31	0.72	6.03	9.57
LL1H	688	14.81	4.36	6.60	23.94	0.13	0.5434	1076	14.94	4.40	6.70	24.00
	45	8.41			7.56	1.02	<0.0001	129	9.43			8.97
LL2A	0					0.00	N/A	0				
LL2B	0					0.00	N/A	0				
LL2C	0					0.00	N/A	0				
LL2D	1	6.26	.	6.26	6.26	0.43	N/A	4	6.69	0.44	6.21	7.27
LL2E	1	6.89	.	6.89	6.89	-0.35	N/A	13	6.54	0.33	6.02	7.07
LL2F	11	7.08	0.68	6.08	8.01	0.05	0.7924	69	7.14	0.60	6.02	8.96
LL2G	38	8.03	1.10	6.70	12.62	0.12	0.5419	91	8.15	0.96	6.03	10.44
LL2H	694	15.19	4.18	6.60	23.94	0.24	0.2422	1085	15.42	4.13	7.29	24.00
	146	9.74			11.30	-0.28	0.0005	135	9.46			10.44
LL3A	0					0.00	N/A	0				
LL3B	0					0.00	N/A	0				
LL3C	1	6.34	.	6.34	6.34	0.68	N/A	6	7.02	1.09	6.17	9.19
LL3D	14	7.12	0.70	6.08	8.64	-0.27	0.1782	49	6.85	0.63	6.02	9.52
LL3E	31	7.76	0.84	6.55	10.84	-0.29	0.0762	117	7.47	0.80	6.02	10.54
LL3F	81	8.69	1.03	6.60	11.27	0.23	0.0894	181	8.92	1.01	6.34	11.34
LL3G	82	10.49	1.29	7.26	14.90	0.50	0.0235	154	10.99	1.74	7.72	19.59
LL3H	611	16.36	3.59	8.62	23.94	0.33	0.0773	935	16.68	3.52	8.62	24.00
	322	12.50			14.34	1.25	0.2554	452	13.75			16.21
LL4A	0					0.00	N/A	0				
LL4B	0					0.00	N/A	0				
LL4C	2	6.93	0.95	6.26	7.61	0.05	0.9333	11	6.99	0.76	6.43	9.19
LL4D	44	7.61	0.90	6.08	10.74	-0.50	0.0003	119	7.11	0.69	6.02	9.41
LL4E	47	8.29	1.08	6.89	11.11	-0.05	0.7650	127	8.25	0.88	6.34	10.54
LL4F	84	9.70	1.17	6.96	12.59	0.26	0.1039	190	9.96	1.21	7.56	14.34
LL4G	74	11.30	1.51	8.54	15.05	0.45	0.0419	135	11.75	1.51	9.12	17.05
LL4H	621	16.96	3.64	9.66	23.94	0.26	0.1527	894	17.22	3.43	9.64	24.00
	219	13.13			15.03	1.02	<0.0001	391	14.15			16.25

Table 45. Summary Data for UL5, UL6 and UL7 in Males

	Results for UL5, UL6 & UL7 Stages A-H for Males - and Censored Stage H (blue)											
	Black British					difference between Means	**p value** T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max			n	Mean Median	SD	Min	Max
UL5A	0					0.00	N/A	0				
UL5B	0					6.38	N/A	3	6.38	0.37	6.04	6.78
UL5C	11	6.85	0.70	6.16	8.49	0.13	0.6215	53	6.98	0.80	6.03	9.81
UL5D	61	8.22	0.89	6.39	10.60	-0.27	0.0519	190	7.96	0.95	6.01	10.85
UL5E	47	9.14	0.77	7.73	10.62	0.23	0.1566	84	9.37	0.97	6.81	11.87
UL5F	67	10.81	1.56	8.12	17.67	0.28	0.2041	127	11.09	1.38	7.65	16.02
UL5G	104	11.83	1.63	8.25	15.85	0.85	0.0001	150	12.68	1.78	9.25	19.59
UL5H	487	17.95	3.35	9.40	23.99	0.60	0.0016	799	18.55	3.28	9.58	23.95
	153	14.22			15.85	1.40	<0.0001	349	15.62			18.00
UL6A	0					0.00	N/A	0				
UL6B	0					0.00	N/A	0				
UL6C	0					0.00	N/A	0				
UL6D	0					7.02	N/A	2	7.02	0.34	6.78	7.26
UL6E	1	6.16	.	6.16	6.16	0.13	N/A	4	6.29	0.32	6.04	6.75
UL6F	8	7.21	0.72	6.26	8.13	-0.43	0.1090	28	6.78	0.64	6.03	9.01
UL6G	69	8.49	1.27	6.21	13.40	-0.16	0.4774	219	8.33	1.68	6.01	16.21
UL6H	769	15.94	4.27	7.39	23.99	0.37	0.0562	1314	16.31	4.29	7.18	23.95
	184	10.48			12.27	0.69	<0.0001	378	11.17			13.28
UL7A	0					11.19	N/A	1	11.19		11.19	11.19
UL7B	0					7.38	N/A	3	7.38	0.57	6.72	7.74
UL7C	15	7.50	1.31	6.16	11.56	-0.55	0.0388	55	6.96	0.74	6.01	9.39
UL7D	39	7.94	0.88	6.21	9.52	-0.33	0.0171	147	7.61	0.73	6.03	9.55
UL7E	96	9.26	1.02	7.39	12.19	0.22	0.1122	195	9.48	1.18	6.74	13.97
UL7F	69	11.22	1.61	8.70	16.66	0.43	0.0716	136	11.65	1.62	7.58	16.21
UL7G	183	12.97	2.02	8.25	22.67	0.40	0.0332	262	13.37	1.85	9.38	19.59
UL7H	475	18.57	2.98	11.32	23.99	0.46	0.0068	816	19.04	2.96	9.58	23.95
	265	16.51			19.05	0.23	0.4614	388	16.74			18.93

Table 46. Summary Data for UL5, UL6 and UL7 in Females

	Results for UL5, UL6 & UL7 Stages A-H for Females - and Censored Stage H (blue)											
	Black British					difference between Means	**p value** T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max			n	Mean Median	SD	Min	Max
UL5A	0					0.00	N/A	0				
UL5B	1	6.26		6.26	6.26	-0.25	N/A	1	6.02		6.02	6.02
UL5C	9	7.52	2.08	6.08	12.89	-0.69	0.0448	50	6.83	0.55	6.02	8.28
UL5D	69	7.99	1.08	6.45	13.82	-0.04	0.7903	163	7.95	1.02	6.10	11.44
UL5E	38	9.18	1.51	6.60	15.51	-0.28	0.2172	92	8.90	1.01	6.34	11.71
UL5F	48	10.33	1.59	6.97	15.95	0.34	0.1571	109	10.67	1.30	7.87	14.05
UL5G	81	11.50	2.01	7.81	19.92	0.70	0.0125	139	12.20	1.98	7.72	22.87
UL5H	632	17.91	3.62	9.66	23.94	0.35	0.0568	816	18.26	3.42	10.43	24.00
	281	14.63			17.51	0.80	<0.0001	398	15.43			18.10
UL6A	0					0.00	N/A	0				
UL6B	0					0.00	N/A	0				
UL6C	0					0.00	N/A	0				
UL6D	0					0.00	N/A	0				
UL6E	2	6.41	0.20	6.26	6.55	1.36	0.2124	7	7.77	1.33	6.47	9.52
UL6F	5	6.86	0.34	6.45	7.35	-0.03	0.9612	19	6.84	1.20	6.02	11.21
UL6G	57	8.40	1.78	6.08	18.18	-0.19	0.4080	223	8.20	1.52	6.12	16.71
UL6H	890	16.26	4.50	6.87	23.94	0.01	0.9701	1343	16.27	4.40	6.36	24.00
	298	11.39			13.71	-0.56	<0.0001	343	10.83			12.74
UL7A	0					0.00	N/A	0				
UL7B	0					7.53	N/A	6	7.53	1.28	6.02	9.19
UL7C	11	7.41	1.24	6.08	9.62	-0.52	0.1859	52	6.89	1.15	6.02	14.34
UL7D	38	8.03	0.88	6.70	9.88	-0.35	0.0670	131	7.69	1.05	6.10	13.50
UL7E	95	8.67	1.19	6.60	11.85	0.44	0.0045	174	9.12	1.23	6.70	14.66
UL7F	65	10.63	1.25	7.25	14.49	0.41	0.0900	120	11.04	1.68	7.72	16.71
UL7G	189	13.14	2.14	7.81	19.92	0.12	0.5544	308	13.26	2.13	8.76	19.45
UL7H	589	18.66	3.31	10.08	23.94	0.38	0.0294	820	19.03	3.10	10.52	24.00
	334	16.52			19.56	0.30	0.0990	425	16.82			19..45

Table 47. Summary Data for LL5, LL6 and LL7 in Males

	Results for LL5, LL6 & LL7 Stages A-H for Males - and Censored Stage H (blue)											
	Black British						p value T tests	White British				
TDS	n	Mean Median	SD	Min	Max	difference between Means	M-W tests	n	Mean Median	SD	Min	Max
LL5A	0					7.37	N/A	2	7.37	1.88	6.04	8.70
LL5B	0					7.26	N/A	5	7.26	1.30	6.08	9.39
LL5C	11	7.05	0.62	6.16	8.05	0.01	0.9581	62	7.06	0.71	6.01	9.31
LL5D	66	8.18	0.96	6.21	10.78	-0.15	0.3126	176	8.03	1.06	6.05	11.21
LL5E	183	12.97	2.02	8.25	22.67	0.40	0.0332	262	13.37	1.85	9.38	19.59
LL5F	111	10.78	1.37	7.69	15.85	0.40	0.0166	201	11.18	1.41	8.27	15.09
LL5G	95	12.37	1.42	8.25	15.85	0.69	0.0003	150	13.06	1.42	10.48	18.47
LL5H	513	18.04	3.34	9.71	23.99	0.72	0.0001	788	18.76	3.16	9.58	23.95
	152	14.30			15.85	1.21	<0.0001	281	15.51			17.31
LL6A	0					0.00	N/A	0				
LL6B	0					0.00	N/A	0				
LL6C	0					0.00	N/A	0				
LL6D	0					6.78	N/A	1	6.78		6.78	6.78
LL6E	1	6.16		6.16	6.16	0.70	N/A	4	6.87	1.04	6.04	8.28
LL6F	10	7.07	0.71	6.21	8.13	0.25	0.5492	67	7.33	1.29	6.03	13.07
LL6G	77	8.38	1.03	6.54	11.37	-0.06	0.7438	224	8.32	1.52	6.01	16.21
LL6H	785	15.88	4.27	7.64	23.99	0.46	0.0160	1359	16.34	4.30	6.77	23.95
	141	10.06			11.32	0.95	<0.0001	361	11.01			12.88
LL7A	0					0.00	N/A	0				
LL7B	0					6.54	N/A	3	6.54	0.43	6.04	6.82
LL7C	12	6.93	0.64	6.16	8.05	0.29	0.3320	85	7.22	0.98	6.01	12.73
LL7D	40	7.98	1.03	6.21	11.20	-0.07	0.7013	124	7.91	0.95	6.03	11.29
LL7E	96	9.21	0.96	7.69	11.99	0.16	0.2463	186	9.37	1.16	6.47	13.97
LL7F	117	11.28	1.36	8.65	16.66	0.46	0.0048	204	11.74	1.42	8.27	16.21
LL7G	149	13.24	1.66	8.25	18.73	0.68	0.0001	265	13.92	1.64	9.59	18.89
LL7H	479	18.73	2.90	11.44	23.99	0.56	0.0006	776	19.29	2.79	9.58	23.95
	216	16.24			18.21	0.64	<0.0001	338	16.88			18.79

Table 48. Summary Data for LL5, LL6 and LL7 in Females

	Results for LL5, LL6 & LL7 Stages A-H for Females - and Censored Stage H (blue)											
	Black British						**p value** T tests M-W tests	White British				
TDS	n	Mean Median	SD	Min	Max	difference between Means		n	Mean Median	SD	Min	Max
LL5A	0					0.00	N/A	0				
LL5B	1	6.26		6.26	6.26	0.65	N/A	6	6.92	0.88	6.31	8.68
LL5C	5	7.83	2.48	6.08	12.06	-0.83	0.0866	59	7.00	0.84	6.02	9.57
LL5D	69	8.05	1.22	6.34	14.86	-0.16	0.3224	155	7.89	1.04	6.22	11.44
LL5E	189	13.14	2.14	7.81	19.92	0.12	0.5544	308	13.26	2.13	8.76	19.45
LL5F	101	10.19	1.37	7.26	14.11	0.61	0.0006	206	10.80	1.48	7.72	15.34
LL5G	94	12.06	1.56	9.35	15.92	0.85	0.0002	142	12.91	1.79	8.76	19.56
LL5H	652	18.02	3.52	9.96	23.95	0.56	0.0015	834	18.58	3.25	11.55	23.98
	205	13.93			15.89	1.78	<0.0001	379	15.71			18.26
LL6A	0					0.00	N/A	0				
LL6B	0					0.00	N/A	0				
LL6C	0					0.00	N/A	0				
LL6D	0					0.00	N/A	0				
LL6E	3	8.58	3.49	6.26	12.59	-0.93	0.6903	3	7.66	1.35	6.66	9.19
LL6F	7	6.99	0.87	6.08	8.75	0.01	0.9868	51	7.00	0.98	6.02	11.34
LL6G	66	7.97	0.93	6.34	10.64	0.11	0.5476	218	8.08	1.41	6.10	16.96
LL6H	923	16.13	4.45	6.87	23.94	0.14	0.4455	1412	16.27	4.41	6.36	24.00
	118	9.43			10.60	1.10	<0.0001	333	10.53			12.30
LL7A	0					0.00	N/A	0				
LL7B	1	7.97		7.97	7.97	-0.93	N/A	5	7.04	1.23	6.02	9.19
LL7C	7	7.29	1.38	6.08	9.87	-0.20	0.6415	81	7.09	1.06	6.02	13.52
LL7D	45	7.68	0.76	6.34	9.67	0.22	0.1894	125	7.89	1.00	6.03	10.47
LL7E	84	8.74	1.05	6.60	11.28	0.36	0.0101	153	9.10	1.02	6.50	12.10
LL7F	95	10.68	1.26	7.25	14.86	0.44	0.0129	176	11.11	1.44	7.72	16.71
LL7G	171	12.95	1.71	9.44	18.18	0.69	0.0001	312	13.63	1.83	8.76	18.91
LL7H	615	18.62	3.22	10.08	23.95	0.65	0.0001	812	19.27	2.91	10.44	24.00
	268	15.69			18.09	1.05	<0.0001	360	16.74			18.89

Figure 43 shows a box and whisker graph of the Stages C-H for the UL7 in males and females respectively illustrating that White British males and females show earlier ages for TDS C and D compared to Black British males and female, but from Stage D onwards and significantly by Stage G, the Black British group have overtaken the White British in the timing of UL7 development. The graph suggests that the overall development of UL7 may occur over a shorter period in the Black British group, possibly establishing later than the White British group but certainly finishing earlier. The age limitation of six years in this sample does not allow Stages A and B to be compared.

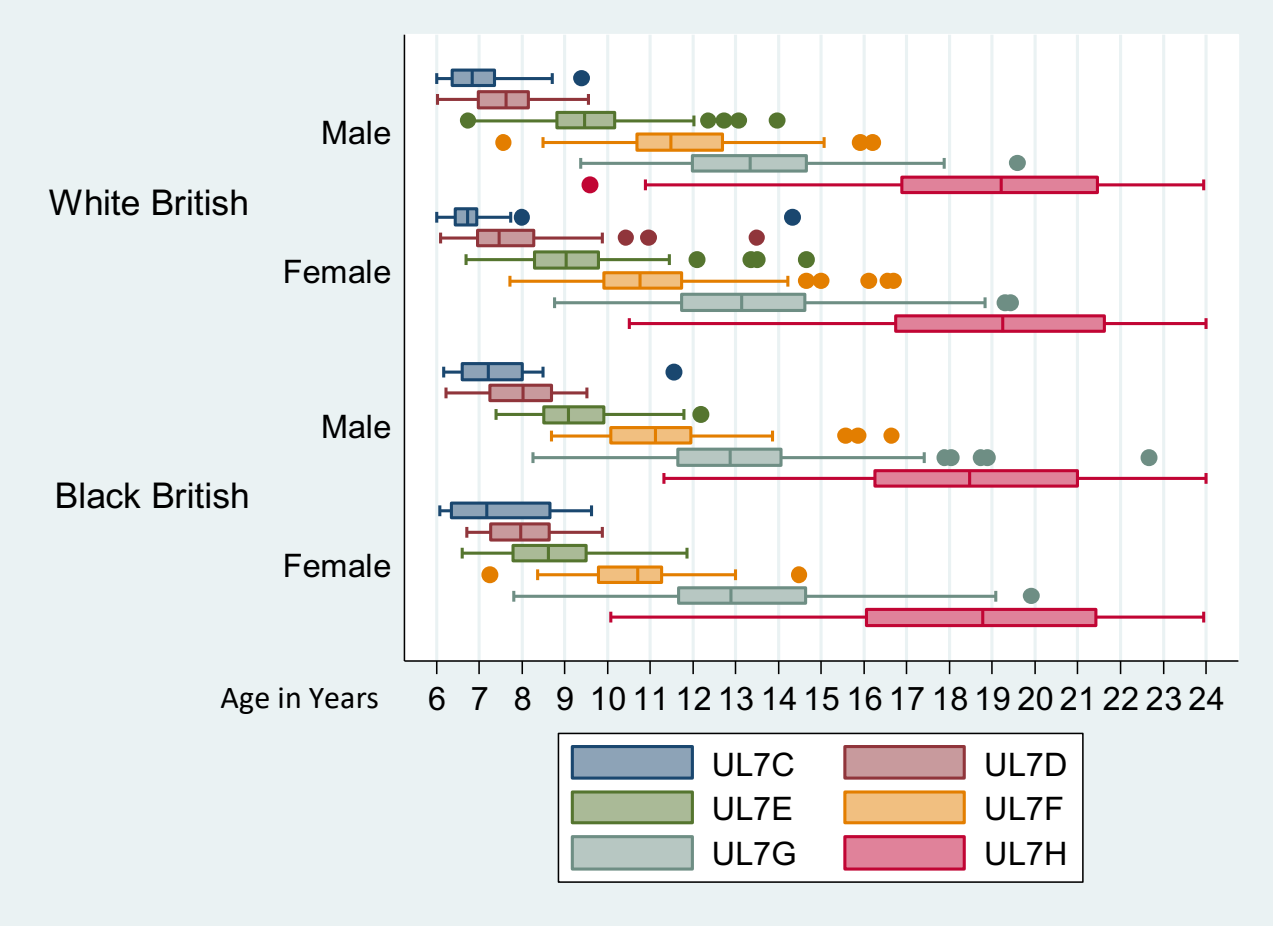


Figure 43. Graph to show the developmental timing of the UL7 in Black British and White British males and females.

These results show that there are ethnic differences not only in third molars but also in other left-sided teeth as most, but not all, TDSs in the Black British group occur at a younger age than in White British. The age range of the sample made comparison of the early TDSs in teeth anterior to the third molar impossible to compare and the middle stages were also not

well represented. However, in terms of mean age for each TDS, Black British males were significantly younger than White British males in the later development, Stages G and H, of the UL1, LL4, UL5, LL5 and LL7 ($p<0.05$). Black British females were significantly ahead of White British females in Stages G and H of the UL1, UL2, UL3, UL4, LL4, UL5, LL5 and LL7 ($p<0.05$). However, this trend was reversed with White British ahead for the mean ages for Stage H of the LL1, LL2, UL2 and UL4 in males, Stage H for the LL2 and UL6 in females, Stages D and E of LL3 in males, Stage D of LL4 in females, Stages C and D of UL7 in males, and Stage C of UL5 in females ($p<0.05$).

Possible differences in the tempo of dental development are suggested by these results but a longitudinal study is required to understand this. The term tempo refers to a pattern of acceleration and deceleration in the timing of dental development, and this may differ between the two ethnic groups.

These results, including those for third molars, can be illustrated by showing the most commonly found Stages of the left-sided teeth, and right-sided third molars, for each yearly age group. This way of showing the pattern of dental development is similar to the stacked bar graphs in Chapter 3 but has information for 18 teeth for each year group. This approach can be illustrated in the style of an atlas.

4.8 An atlas approach to the data

Atlas systems are valuable in archaeological, anthropological, or mass disaster situations where this type of readily accessible and straightforward reference guide is widely accepted as of real practical assistance. Using the data output for the stacked bar charts, for example, the average LL8 TDS for 12-year-old Black British males is Stage D (Figure 33 on page 138), while for 12-year old White British males it is Stage C (Figure 35 on page 139). This data can be produced for all teeth on the left side, and all third molars, for each year group. Employing pictorial representations of the average TDS seen at each year group, an atlas system for DAE applicable to males and females in both ethnic groups can be drawn up. To find the average TDS for a certain year group, the mode, i.e. the most frequently occurring TDS, is the most relevant average to consider. Table 49 shows an example of this for the UL5

TDS A-H in Black British males with Figure 44 showing this data used to create a stacked bar graph similar to those shown earlier for the LL8 (Figures 33-37).

Table 49. UL5 TDS A-H in Black British (BB) males.

BB MALES UL5 TDS	Age (yrs)	6	7	8	9	10	11	12	13	14	15	16
	H	0	0	0	1	2	7	20	37	45	49	47
	G	0	0	3	11	21	24	15	21	5	4	0
	F	0	0	9	9	18	18	9	3	0	0	0
n	E	0	4	13	23	7	0	0	0	0	0	0
	D	4	20	23	13	1	0	0	0	0	0	0
	C	8	2	1	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0
	A	0	0	0	0	0	0	0	0	0	0	0
	Total n	12	26	49	57	49	49	44	61	50	53	47
	Age (yrs)	6	7	8	9	10	11	12	13	14	15	16
	H	0	0	0	2	4	14	45	61	90	92	100
	G	0	0	6	19	43	49	34	34	10	8	0
	F	0	0	18	16	37	37	20	5	0	0	0
calculated %'s	E	0	15	27	40	14	0	0	0	0	0	0
	D	33	77	47	23	2	0	0	0	0	0	0
	C	67	8	2	0	0	0	0	0	0	0	0
	B	0	0	0	0	0	0	0	0	0	0	0
	A	0	0	0	0	0	0	0	0	0	0	0
	Total %	100	100	100	100	100	100	100	100	100	100	100
	MODE TDS	C	D	D	E	G	G	H	H	H	H	H

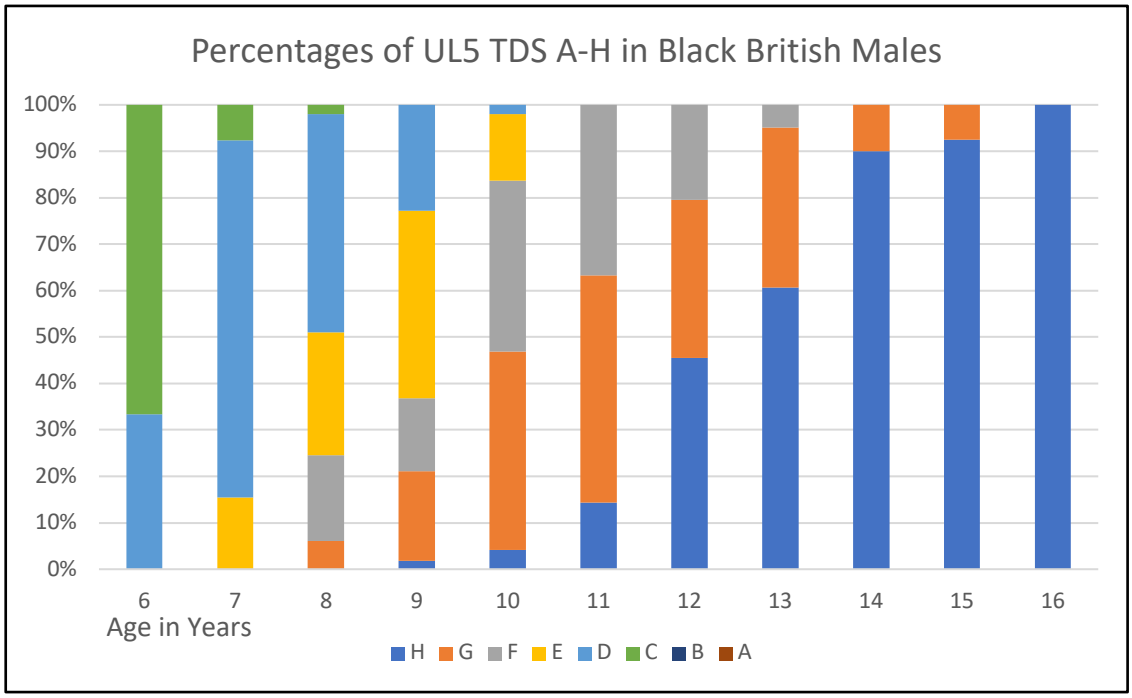


Figure 44. Stacked bar graph to show percentages of UL5 TDS A-H in Black British males by age in years.

Tables 50 and 51 show the mode average TDS for teeth on the left side and third molars for yearly age groups in Black British and White British males and females from data derived similarly to that in the example above. Tables 52-55 show these results arranged in an atlas style configuration using letters rather than pictorial illustrations for TDS.

Table 50. Table to show mode TDS of upper left sided teeth and third molars in each year group.

	AGE IN YEARS																	
UL1	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	E	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	E	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	F	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
UL2	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	E	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	D	F	F	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
UL3	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	D	E	F	F	F	G	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	D	E	F	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	D	E	F	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H
UL4	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	D	E	F	G	G	G	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	D	E	E	F	G	G	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	D	E	F	F	G	G	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	E	F	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H
UL5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	D	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	C	D	D	E	F	G	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	C	D	D	E	G	G	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	D	E	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H
UL6	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
UL7	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	D	E	E	E	G	G	G	G	H	H	H	H	H	H	H	H	H
WB FEMALES	D	D	E	E	F	G	G	G	G	H	H	H	H	H	H	H	H	H
BB MALES	D	D	E	E	F	G	G	G	H	H	H	H	H	H	H	H	H	H
BB FEMALES	E	E	E	E	G	G	G	H	H	H	H	H	H	H	H	H	H	H
UL8	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	BLANK	A	B	B	C	C	D	D	E	E	F	G	H	H	H	H	H	H
WB FEMALES	A	A	B	C	C	C	D	D	E	E	E	F	G	H	H	H	H	H
BB MALES	BLANK	B	B	B	C	D	D	D	E	F	G	H	H	H	H	H	H	H
BB FEMALES	A	B	B	C	C	D	D	D	E	F	G	H	H	H	H	H	H	H

Table 51. Table to show mode TDS of lower left sided teeth and third molars in each year group

	AGE IN YEARS																	
LL1	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
LL2	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	F	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
LL3	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	E	E	F	F	F	G	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	E	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	D	E	F	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	F	F	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H
LL4	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	D	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	D	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	D	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H	H
LL5	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	C	D	D	E	F	F	G	G	H	H	H	H	H	H	H	H	H	H
WB FEMALES	C	D	E	F	F	F	F	G	H	H	H	H	H	H	H	H	H	H
BB MALES	D	D	E	F	F	F	F	G	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	D	E	F	F	G	H	H	H	H	H	H	H	H	H	H	H	H
LL6	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
WB FEMALES	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB MALES	G	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
BB FEMALES	G	G	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
LL7	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	C	D	E	E	F	F	G	G	G	H	H	H	H	H	H	H	H	H
WB FEMALES	C	D	E	E	F	F	G	G	G	H	H	H	H	H	H	H	H	H
BB MALES	C	D	E	E	F	F	G	G	H	H	H	H	H	H	H	H	H	H
BB FEMALES	D	D	E	F	F	F	G	H	H	H	H	H	H	H	H	H	H	H
LL8	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**
WB MALES	BLANK	A	A	B	B	C	C	C	D	E	E	F	G	H	H	H	H	H
WB FEMALES	BLANK	A	A	B	B	C	C	C	D	E	E	F	G	H	H	H	H	H
BB MALES	BLANK	A	B	B	C	C	D	E	E	F	G	G	H	H	H	H	H	H
BB FEMALES	A	A	B	C	C	C	D	E	E	F	F	G	G	H	H	H	H	H

Table 52. Table to show atlas style configuration of mode TDS of left sided teeth of White British at 6, 7, 8, 9, 10, 11, and 12 years of age.

WHITE BRITISH MALES									WHITE BRITISH FEMALES								
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	E	D	D	D	D	G	D	0		F	E	D	D	C	G	D	A
6 YEARS	G	F	D	D	C	G	C	0		G	F	E	D	C	G	C	0
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	F	E	D	D	D	G	D	A		F	F	E	E	D	G	D	A
7 YEARS	G	F	E	D	D	G	D	A		G	G	E	D	D	G	D	A
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	G	F	E	E	D	G	E	B		G	F	F	E	D	G	E	B
8 YEARS	H	G	E	E	D	G	E	A		H	G	F	E	E	G	E	A
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	H	G	F	F	E	H	E	B		H	G	F	F	E	H	E	C
9 YEARS	H	H	F	F	E	H	E	B		H	H	F	F	F	H	E	B
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	H	H	F	G	F	H	E	C		H	H	F	G	F	H	F	C
10 YEARS	H	H	F	F	F	H	F	B		H	H	G	F	F	H	F	B
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	H	H	F	G	F	H	G	C		H	H	G	G	G	H	G	C
11 YEARS	H	H	F	G	F	H	F	C		H	H	H	G	F	H	F	C
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8
AGE	H	H	G	G	G	H	G	D		H	H	H	H	H	H	G	D
12 YEARS	H	H	G	H	G	H	G	C		H	H	H	H	F	H	G	C
	1	2	3	4	5	6	7	8		1	2	3	4	5	6	7	8

Table 53. Table to show atlas style configuration of mode TDS of left sided teeth of White British at 13, 14, 15, 16, 17, 18, and 19 years of age.

	WHITE BRITISH MALES								WHITE BRITISH FEMALES							
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	G	D	H	H	H	H	H	H	G	D
13 YEARS	H	H	H	H	G	H	G	C	H	H	H	H	G	H	G	C
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	G	E	H	H	H	H	H	H	G	E
14 YEARS	H	H	H	H	H	H	G	D	H	H	H	H	H	H	G	D
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	H	E	H	H	H	H	H	H	H	E
15 YEARS	H	H	H	H	H	H	H	E	H	H	H	H	H	H	H	E
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	H	F	H	H	H	H	H	H	H	E
16 YEARS	H	H	H	H	H	H	H	E	H	H	H	H	H	H	H	E
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	H	G	H	H	H	H	H	H	H	F
17 YEARS	H	H	H	H	H	H	H	F	H	H	H	H	H	H	H	F
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	G
18 YEARS	H	H	H	H	H	H	H	G	H	H	H	H	H	H	H	G
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8
AGE	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
19 YEARS	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H	H
	1	2	3	4	5	6	7	8	1	2	3	4	5	6	7	8

Table 54. Table to show atlas style configuration of mode TDS of left sided teeth of Black British at 6, 7, 8, 9, 10, 11, and 12 years of age.

BLACK BRITISH MALES		BLACK BRITISH FEMALES	
AGE 6 YEARS	1 2 3 4 5 6 7 8 E D D D C G D 0 G F D D D G C 0 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 F F D D D G E A G F D D D G D A 1 2 3 4 5 6 7 8
AGE 7 YEARS	1 2 3 4 5 6 7 8 F F E E D G D B H G E D D G D A 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 G F E E D G E B H G F E D G D A 1 2 3 4 5 6 7 8
AGE 8 YEARS	1 2 3 4 5 6 7 8 G F F F D G E B H H F E E G E B 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 G G F F E H E B H H F F E H E B 1 2 3 4 5 6 7 8
AGE 9 YEARS	1 2 3 4 5 6 7 8 H H F F E H E B H H F F F H E B 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H F G F H E C H H G F F H F C 1 2 3 4 5 6 7 8
AGE 10 YEARS	1 2 3 4 5 6 7 8 H H F G G H F C H H F F F H F C 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H G G G H F C H H G G F H F C 1 2 3 4 5 6 7 8
AGE 11 YEARS	1 2 3 4 5 6 7 8 H H G G G H G D H H G G F H F C 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H G D H H H H G H F C 1 2 3 4 5 6 7 8
AGE 12 YEARS	1 2 3 4 5 6 7 8 H H H H H H G D H H H H F H G D 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H G D H H H H H H G D 1 2 3 4 5 6 7 8

Table 55. Table to show atlas style configuration of mode TDS of left sided teeth of Black British at 13, 14, 15, 16, 17, 18, and 19 years of age.

BLACK BRITISH MALES		BLACK BRITISH FEMALES	
AGE 13 YEARS	1 2 3 4 5 6 7 8 H H H H H H G D H H H H H H G E 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H D H H H H H H H E 1 2 3 4 5 6 7 8
AGE 14 YEARS	1 2 3 4 5 6 7 8 H H H H H H H E H H H H H H H E 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H E H H H H H H H E 1 2 3 4 5 6 7 8
AGE 15 YEARS	1 2 3 4 5 6 7 8 H H H H H H H F H H H H H H H F 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H F H H H H H H H F 1 2 3 4 5 6 7 8
AGE 16 YEARS	1 2 3 4 5 6 7 8 H H H H H H H G H H H H H H H G 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H G H H H H H H H F 1 2 3 4 5 6 7 8
AGE 17 YEARS	1 2 3 4 5 6 7 8 H H H H H H H H H H H H H H H G 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H H H H H H H H H G 1 2 3 4 5 6 7 8
AGE 18 YEARS	1 2 3 4 5 6 7 8 H H H H H H H H H H H H H H H H 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H H H H H H H H H G 1 2 3 4 5 6 7 8
AGE 19 YEARS	1 2 3 4 5 6 7 8 H H H H H H H H H H H H H H H H 1 2 3 4 5 6 7 8		1 2 3 4 5 6 7 8 H H H H H H H H H H H H H H H H 1 2 3 4 5 6 7 8

The above tables reflect that after the age of 13 in Black British, and 15 in White British, the only developing teeth are the third molars. The age range, as shown previously, is wide and often extends to eight or nine years for third molars although for the left-sided teeth in general, 3SD from the mean generally extends to a range of about 3-5 years. Wide age ranges negatively affect accuracy and are a significant limitation in all DAE methods. However, DAE scenarios where an atlas method may be required, and legal thresholds are not under consideration, can accommodate some degree of inaccuracy. By replacing the TDS alphabetical categorisation with line drawings based on the originals drawn by Demirjian, Goldstein and Tanner [65, 288] (Figure 1 on page 25, and Figure 18 on page 110), a pictorial impression of the dentition can be produced. An example of a true atlas illustration is given in Figure 45 which shows the left-sided teeth at age 11 in Black British and White British males and females.

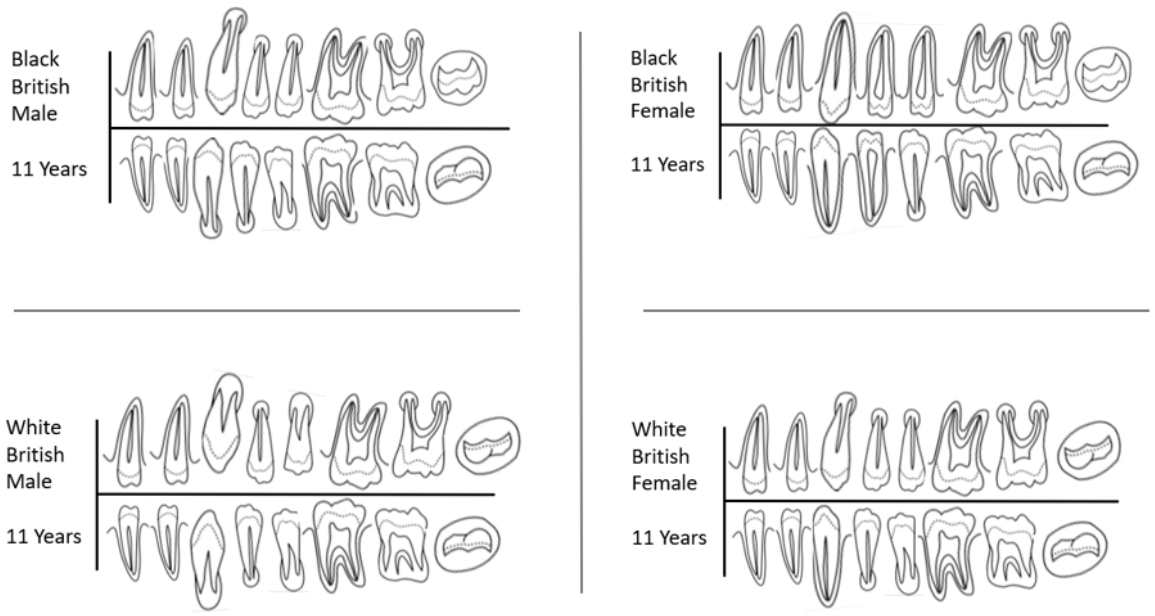


Figure 45. Atlas illustration of left-sided teeth at age 11 in Black British and White British males and females. (Permission for reproduction of TDS line drawings granted by Wayne State University.)

Chapter 5

Discussion

5.1 General Discussion

The sample size is very large for a study of this kind. The age distribution has been as uniformly structured as possible, only limited by the number of DPTs of Black British or subjects of other Black ancestry available in the GSTT Romexis® database. The sample is likely to include all subjects who have registered their ethnicity as Black and have a DPT on the database which spans the period from 2005 to February 2020. These subjects represent about 12% of the total which seems to be less than expected when the Southwark Black population is more of the order of 20%. This could be because of reluctance to register an ethnicity or because fewer DPTs are required of this population group. Reasons for the latter might include fewer orthodontic problems, less overcrowding, less hypodontia, fewer third molar impactions, fewer syndromic dental conditions, less generalised dental disease, or lack of access to or attendance for specialist dental care, compared to other ethnic groups. As all subjects in the study have attended GSTT as a result of geographical convenience and the same referral pathways, differences in the timing of dental development cannot easily be attributed to geographical, dietary, lifestyle, cultural or socio-economic differences. It is therefore reasonable to conclude that the differences are mainly attributable to genetic factors. Inevitably, clerical errors in hospital records are likely to have led to several erroneous results. Similarly, the possibility of such errors by the observer must be conceded, but the sample size is considered large enough to compensate for these influences. There is no reason to believe that there are intentional inaccuracies with reported dates of birth. Although it is possible that some individuals were not born in the UK, it is far more likely that they were.

With the importance of ethnicity in DAE, especially at the 18-year-old threshold, still debated, the main aim of the study was to find out if an ethnic difference exists in third molar development. The study was designed to investigate and compare features which could affect DAE, especially the timing of dental development, in Black British and White British groups. Comparison of mean ages for TDS has been the basis of numerous publications [268, 289, 291, 292] and this manageable and unambiguous approach was agreed for the comparison of the two ethnic groups in the present study. No attempt was made to compare dental age with chronological age or to present results in such a way to indicate support for DAE to establish legal age thresholds. Conversely, notwithstanding the clear ethnic difference demonstrated, the findings confirm large age ranges at TDSs which show that the level of accuracy required for DAE regarding legal thresholds is impossible. Having demonstrated highly significant ethnic differences in third molar development, in its timing and in the prevalence of agenesis, the effects of developmentally missing teeth were investigated. All teeth on the left side were also compared in order to understand ethnic differences in the dentition as a whole. The findings suggested potential for an ethnically appropriate atlas approach to DAE in settings where life-changing establishment of legal thresholds is not the priority.

5.2 The timing of dental development

The results show a highly significant ethnic difference in the timing of third molar development occurring earlier in the Black British group compared to the White British ethnic group. Mean ages for females were generally at least 1.5 years ahead, and males at least one year ahead, for every Demirjian stage A-H of all third molars. For the lower left third molar the mean ages at Demirjian Stages A-H, in both males and females, were highly significantly different ($p<0.001$). Even in 6-year-olds, despite the limited number of DPTs available for this age group, Black British males and females appear to be significantly in advance of their White British counterparts. This finding lends support to the suggestion that once initiated, tooth formation proceeds at a chronologically regular rate [293] as the results show that, although these individuals are not followed longitudinally, this early advancement appears to persist and be reflected by earlier achievement of Stage H. However, third molars may be subject to acceleration and deceleration during the course of their development as the results also possibly show. The possibility that the development of third molars in different

individuals occurs within different time spans also cannot be ruled out. These features further illustrate that no two individuals will demonstrate exactly the same developmental timing.

In both ethnic groups, the completion of third molar development takes place at a younger age in males compared to females but a pattern of development is apparent whereby the early TDS are seen at a younger age in females compared to males. At around age 12 for the Black British group, and 13 for the White British group, males overtake females in the timing of lower left third molar development (Figures 27, 28 and 29, pages 133-135). Generally, for the timing of third molar stages D-H, these are seen earliest are seen in Black British males, followed by Black British females, White British males, and finally White British females. For the initiation of third molars, it appears that this is seen earliest in Black British females, followed by Black British males, and later in White British males and females. Although investigation is limited by the cross-sectional nature of the study, the total time for third molar development therefore appears longer in females than it is in males because, on a group basis, females reach Stage H before males. This difference appears to be greater in the Black British group. Another explanation could be that the initiation period for girls' third molars has a particularly wide range and completion takes place after approximately the same interval, or it could be that the third molars overall development encompasses a range of speeds which may even vary during development. This feature of a longer span of third molar development in girls has been little, if at all, reported in the literature but it is perhaps not surprising considering the widely reported earlier development of all teeth other than the third molar in girls together with the widely reported earlier completion of third molars in boys. Although now well-established, in an early radiological study by Moorees et al the male-female reversal in third molar development was not discussed although it was found to be the case in every third molar stage [161]. In French Canadians it was found that only the later third molar stages were accelerated in males compared to females [162]. Harris has discussed the tempo of third molar development [207], reflecting a changing speed of development which could also be apparent in the results of the present study. Harris states that growth tempos of tooth formation among ethnic groups do not parallel each other but trajectories vary in complex fashion depending on the stage of development. Without a longitudinal study of third molar development, these features cannot be fully understood.

The patterns of TDS in third molar development could suggest that puberty has an influence. This hypothesis has been suggested [202, 204, 208, 257] but little investigated. This possible view

would be supported by the fact that girls enter puberty earlier than boys and that puberty generally occurs earlier in Black British girls and boys compared to their White British counterparts [210]. The conjecture could be that timing of third molar development may be a reflection of varying hormonal levels during the course of puberty and the ethnic differences that exist in this respect [210].

Harris also makes it clear that while his study of dental development showed that group differences between Black and White ethnicities were readily discernible statistically, an objective researcher would be hard-pressed to support the fractional differences required for a medico-legal decision on a single case basis using the extremely variable formation of the third molar [207]. To illustrate this difficulty. Harris presented a chart showing the large age ranges for each of the 14 Moorrees TDS, of about 6-10 years, and points out that if the Demirjian system were used, the age ranges would be expected to be larger. Harris stated his opinion that the huge ranges defeat any attempt to accurately estimate a person's age [207]. At the planning stage of this study, it was thought that the wide age ranges seen in samples containing several ethnicities could perhaps be narrowed by separating data by ethnicity. This would have had potential to improve accuracy in DAE. In fact, the present study shows that wide age ranges are present in both Black British, an average range for each LL8 TDS of approximately 7 years, and White British groups, approximately 9 years, as shown in Table 12 on page 130 which confirm the wide ranges seen in other studies. Wide age ranges at each TDS, regardless of any sex or ethnic difference, and widening as age progresses, mean that DAE for individual older children and young adults is always prone to considerable uncertainty. Accurate age prediction is impossible as although a dental age can be calculated on the basis of information from a reference group, an age cannot be assigned to an individual on the basis of the average age seen at a certain stage of third molar development because their chronological age could equally well be anywhere within, and possibly outside, the range available in the reference data. As stated by Harris, there is no assurance that any given person will conform to third molar development close to a mean in a reference sample [207]. The large sample in the present study shows age ranges which, inevitably, must be larger in the wider population. Studies based on smaller samples showing smaller age ranges may consequently claim greater, but therefore misplaced, accuracy in DAE. DAE methods which rely on data only within a certain range of the mean also fail to adequately acknowledge individual variation. Moreover, the assumption that TDS data is normally distributed, even in

a large study such as the present one, has been questioned by the present results (Tables 10 and 11).

The stacked bar charts (Figures 31-37, pages 137-140) illustrate some of the difficulties with, for example, DAE at the 18-year-old threshold. It has been claimed, dismissing ethnic differences, that there is a probability of 0.945 (95%) of an individual being over 18 if a lower third molar is fully complete and, on the balance of probabilities, over 18 if a lower third molar is at Stage G or H [241]. The ABFO study claimed that if a lower third molar is at Stage H the probability of being 18 or older is 90.1% for males and 92.2% for females, the difference between Black Americans and White Americans being insignificant [240]. However, for White British males, whilst 61% of 18-year-olds have lower third molars at G or H, so do 43% of 17-year-olds who will also be deemed likely over 18. For Black British males, whilst 88% of 18-year-olds have lower third molars at G or H, so do 75% of 17-year-olds, who would all be deemed likely over 18. Indeed, some White British as well as Black British subjects as young as age 15 have lower third molars at Stage G or H. As discussed earlier, Black British females are in advance of the other groups and there are 13-year-olds with lower third molars at Stage G or H. The results make it clear that if DAE is to be applied, there is a high risk of overestimating the age of children and young adults of Black African ancestry if reference data from individuals of White ancestry is applied. The data presented in the stacked bar charts provides a substantial argument against the use of DAE in living individuals.

In addition to uncertainty due to extensive age ranges for each TDS in both ethnic groups, and as also commented on by Harris [207], it is never possible to consider that anyone has a heterogeneous ethnic background. For these reasons, an ethnically-appropriate dataset, no matter how often it has been cited in recent years as a recommendation, may give important information regarding ethnic variation on a group basis but will not make DAE more valid for establishing the 18-year-old or other similar threshold in an individual. It also does not necessarily follow that people of African ancestry from Africa will conform to the dental characteristics of a Black British population.

Although Bayesian statistics, which are complex and require specialist statistical knowledge, have been advocated in DAE for improved accuracy in presenting the likelihood of an individual reaching an age threshold, the above reasons would seem to outweigh any

advantage in the Bayesian approach. In the present study, the even distribution of age ranges and large sample size offer confidence that the ethnic differences revealed would not be expected to be negated using a Bayesian approach.

5.3 Developmentally missing teeth

GSTT is a centre for hypodontia treatment and therefore the sample will contain many subjects with hypodontia of varying severity. The prevalence of hypodontia (by definition with or without TMA) in the whole sample was 10% and 13% for Black British males and females respectively, and 26% and 28% for White British males and females respectively. Analysis was carried out having excluded subjects with hypodontia because hypodontia is associated with delayed dental development [266, 116, 117], a feature well-accepted by specialists in orthodontics [294]. Highly significant ethnic difference in third molar development persisted in subjects without hypodontia ($p<0.0001$ for the majority of TDS) (Tables 32 and 33). Therefore, although hypodontia may be a factor in the ethnic difference seen in dental maturation as a whole, and indeed be intrinsically affected by ethnic factors, it does not fully explain the difference in the timing of third molar development in the two groups for which the overriding factor appears to be ethnicity. The prevalence of complete dentitions, that is, subjects with all permanent teeth present, in Black British males and females was 80% and 76% respectively and in White British males and females was 49% and 48% respectively. Third molar TDSs compared in subjects with complete dentitions (Tables 39 and 40) confirmed and emphasised the ethnic difference seen in comparisons using the whole sample.

The prevalence of TMA in 12.00-19.99 year-olds was 8% and 11% for Black British males and females respectively, and significantly lower at 31% and 34% for White British males and females respectively (Chi Square test $p = <0.0001$) which was not unexpected according to the literature. The frequency of TMA in males and females is similar with TMA affecting 3% more females and ethnicity did not affect this finding. This study evaluated 2,480 12.00-19.99 year-old subjects for TMA making it a particularly large study of its kind. The results are similar to a study of 1,700 Americans of Black and White ethnicities which found highly significantly less TMA and hypodontia in Black Americans (11%) compared to White Americans (27%) [105]. In that study, third molars were the most commonly absent tooth in

both ethnic groups and were the only tooth type to show sexual dimorphism with more TMA in females in both groups.

When all missing third molars were accounted for, the TMA frequency was seen to be almost equal for each of the four quadrants. In both ethnic groups, where two third molars were missing (3.0% for Black British males and 3.5% for females; and 8.9% for White British males and 9.5% for females), TMA most often affected mandibular molars or maxillary molars, in almost equal proportions, with other combinations rarely seen. In both ethnic groups the most frequent finding was all four third molars present (89% for Black British males and 92% for females; and 68% for White British males and 66% for females) but the next most frequent pattern for White British was all four third molars developmentally missing (males 11%, females 13%), followed by two third molars missing, then three, and most infrequently one third molar missing (males 4.5%, females 4%). In Black British, although overall much less than in White British, the most frequent pattern of TMA was two or three missing third molars.

About one third of the White British 12.00-19.99 year-olds showed hypodontia or oligodontia while this was seen in about 14% of the Black British in this group. Not only is TMA much less prevalent in the Black British group but other missing teeth are seen much more infrequently also. To summarise the relationship between subjects with hypodontia of any severity and their TMA status, it was found that the chance of White British male 12.00-19.99 year-olds having TMA when there is any degree of hypodontia is 64%, and a likelihood of having TMA with hypodontia of 1.6 to 1. For Black British males the probability of having TMA when there is hypodontia is 28%. This means that for Black British males, TMA appears to be more independent of hypodontia. It is speculated that the lower frequencies of hypodontia and TMA seen in the Black British group could be a result of lower frequencies of mutations in genes responsible for tooth agenesis such as MSX1 and PAX9.

Both hypodontia and TMA have been confirmed to be associated with a delay in third molar development in both ethnic groups. There were insufficient numbers of subjects with TMA only to show statistical significance of delayed development of any remaining third molars but the results do suggest this (Tables 36 and 37). As TMA is likely to be associated with a slower timing of dental development as a whole, then DAE reference data which includes

subjects with TMA is likely to result in lower dental ages than in those with complete dentitions. Dental ages of White British would be expected to be younger compared to that of the Black British because TMA prevalence in White British is significantly higher. Furthermore, because of the high incidence of other missing teeth in the White British group, the discrepancy is likely to be further enhanced if such subjects are included in reference data. This, as well as the effect of ethnicity itself which has been shown to be present even if hypodontia is taken into account, would risk overestimation of the chronological age of individuals with African ancestry if White British reference data is used. It also follows that the practice of substituting antimeres when left-sided teeth are missing has a more complicated effect than is recognised and introduces a potential for underestimation of chronological age. The applicability and accuracy of DAE without taking TMA and hypodontia into consideration therefore raises concern.

The DPTs inevitably show a dental problem of some kind and hypodontia may not be the only type of problem that shows an ethnic bias. Third molars exhibit substantial morphological variation and may be affected by a wide range of pathological conditions that could affect their development. Many of the DPTs in the older age groups of the sample were likely to have been taken prior to third molar surgery and therefore may show third molars which lack space in the dental arch and are impacted. Data in this study does not allow any ethnic bias to be revealed in such cases but impacted teeth have been associated with a delay in root development and this is yet another complicating factor in DAE and studies of this kind. Another feature of third molars, however, is that their angulation can change and teeth that appear impacted radiographically, even "hopeless impactions" [70], do not necessarily remain so as growth continues and the prognosis of eventual position is uncertain. It would be a challenge to find a suitable sample of DPTs showing complete dentitions including third molars without impactions or pathological conditions.

5.4 The Dentition as a Whole

The age range of the sample does not allow comparison of the early TDSs in left-sided teeth anterior to the third molar. The middle stages were also not well represented as incisors and first molars, for example, have completed their maturation by the approximate age of nine.

Most later stages of left-sided teeth in Black British were found to occur at a significantly younger age than in White British. However, for several TDSs in several teeth this trend was reversed. The ethnic difference was therefore more complicated in the dentition as a whole which may reflect different tempos of development between ethnicities similar to those suggested by Harris for third molar development [207]. The reasons for this are unclear but may possibly reflect general growth patterns and hormonal influences.

5.5 DAE Considerations

Even aside from ethnic difference, biological variation makes the third molar inadequate for establishing legal age thresholds. Legally, the standard required in Criminal Courts is that of beyond reasonable doubt but this standard cannot be met with DAE. The Civil Court's standard depends on the balance of probabilities but this is not sufficient in these circumstances when benefit of the doubt is the absolute rule and anything less would be an infringement of human rights. The danger of overestimating the age of those of African ancestry if reference data from subjects of White ethnicity is used has been confirmed by the present study. Although an ethnic difference on a group basis is an important finding for decision-makers, DAE for individual older children and young adults is prone to considerable uncertainty regardless of any sex or ethnic difference. The impossibility of defining an ethnic group, together with complicating factors such as hypodontia and TMA, have been discussed and these issues only underline the difficulties with DAE. The new data could be incorporated in a computerised system such as Quicksheets© and arranged so that the user could simply select which ethnic group's data is to be used for the DAE. Using an ethnically-appropriate reference dataset may seem laudable but, for age thresholds certainly, cannot ensure that a valid conclusion is reached because, apart from any other factors, ethnic groups are still characterised by wide individual variability. By separating the results by ethnicity, the age ranges at each TDS were not narrowed as might have been expected.

Although accuracy regarding age thresholds is not improved by this research, an atlas system showing males and females of each ethnic group would be a welcome reference tool for forensic odontologists, anthropologists, and archaeologists [295] to assist with identification of the deceased. In these cases, there are no life-changing consequences dependent on legal age

thresholds. DAE is important for assisting in individual identification in mass disasters or for establishing relative ages in family members or groups of children. The Schour and Massler [71], Logan and Kronfeld [29], and London Atlas [72] are currently used but there are none which separate males, females, and ethnicities. The results of this study show that there are sufficient differences between those groups to contribute to a well-rounded approach to DAE in this context.

5.6 Conclusions

- In, to my knowledge, the largest study of its kind, and the first to compare Black ethnic and White ethnic groups in the United Kingdom, 5,590 subjects allowed ethnic differences to be clearly identified, answering the principal aim of whether there is a demonstrable ethnic difference in dental development, focusing on the third molar, in children and young adults of Black British or other Black ethnicity and White British subjects living in the same area of the UK.

- Highly significant differences in the timing of third molar development between Black British and White British ethnic groups aged 6-24 years have been demonstrated.

- All Demirjian TDSs in all third molars were seen at a younger age in both males and females in the Black British group compared to the White British group. With regard to Stages A-H of third molars, this difference is about one and a half years in females and one year in males.
- The null hypothesis that the age associated with defined third molar development stages in UK subjects is the same in both groups is rejected.

- Fulfilling the second aim of determining whether there is an ethnic difference in the prevalence of developmentally missing teeth, highly significant differences have been demonstrated between Black British and White British ethnic groups.

- TMA was at least three times more likely in White British than in Black British. Hypodontia of any severity, with or without TMA, was approximately twice as likely in the White British group compared to the Black British group. TMA and hypodontia were also slightly more prevalent in females of both ethnic groups.

- The null hypotheses that the prevalence of TMA and hypodontia is the same in both ethnic groups are rejected.

- Four missing third molars was the most common pattern of TMA in White British, followed by two missing third molars. In Black British, the most common presentation of TMA was two missing third molars. In both ethnic groups, the most common pattern of two missing third molars was for either upper or lower third molars to be missing.

- The null hypothesis that developmentally missing teeth do not affect the timing of dental development is rejected.

- Hypodontia has been shown to be associated with slower third molar development compared to that in complete dentitions and the results suggest that TMA without hypodontia similarly affects developmental timing.

- Regardless of ethnicity, various other complicating factors, most importantly the wide age ranges at each TDS, mean that DAE for the determination of age thresholds remains prone to considerable and insurmountable uncertainty.

- Apart from third molars, TDSs of left-sided teeth generally occurred at younger ages in the Black British group compared to the White British group, especially at later TDSs, but this trend was reversed in several TDSs in several teeth showing a less than straightforward ethnic difference in development of teeth anterior to third molars.

- While it is impossible to accurately establish attainment of the 18-year-old threshold using DAE, the ethnic difference on a group basis is an important finding to be considered in this regard.

- There could be significant value in a new atlas approach showing separate results for both ethnic groups, also separating males and females, for use when age thresholding is not the issue.

- The ethnic differences found are unlikely to be attributable to sample size, data management, geographical, dietary, or socio-economic circumstances and the genetic component appears to prevail.

- The UK data may not accurately apply to populations in Africa but the research confirms that ethnicity does matter when considering DAE.

Chapter 8

Future Work

This research has confirmed the answers to questions about dental development and ethnicity which have been the subject of debate for many years but has also highlighted several areas requiring further investigation.

A validation study could be carried out using, for example, data from King's College Hospital where ethnic demographics would be expected to be similar to at GSTT. This would involve a sample of Black British or other Black ethnicity and White British with similar data collected for comparison with this study. A sample of DPTs with minimal pathological features would be even more preferable for a study. These could possibly be available in a general practice setting but it would be difficult to find them in sufficient numbers.

An atlas for each year group of Black African ethnicity and White ethnicity, males and female, based on the Black British and White British group data in this study could be prepared and made available to the forensic community to assist with age estimation at time of death and hence identification of unknown individuals in situations such as mass disasters.

A study could be carried out to compare chronological age with dental age found using a system similar to Quicksheets© containing a RDS generated from the data collected for this study. While its use for establishment of age thresholds would not be endorsed by this author because incontrovertible wide age ranges at TDSs would make it unreliable, such a study would allow the accuracy of DAE with the new data to be investigated.

The large dataset compiled holds much information which could be further analysed.

This study included data collection for MMMs. Inter- and intra-rater testing of MMM Stages is required before this data can be presented. Preliminary results showed ethnic variation in MMM Stages, with the Black British group again ahead of the White British group. More research is also required to explain why these changes are apparent on DPTs when the tooth anatomy itself does not change.

More work is required to investigate possible associations between the timing of dental development, hypodontia, and TMA.

The data would also allow patterns of hypodontia to be investigated such as the frequency of tooth types and combinations of teeth affected by hypodontia in each ethnic group. The relationships between hypodontia and TMA in the same quadrants, for example, could be investigated.

Hypodontia and hyperdontia could be further investigated not only in terms of frequencies but also to assist in finding reasons for their occurrence. Literature about hyperdontia, especially its effect on the developmental timing, is extremely sparse.

The tempo, or pattern of acceleration and deceleration, in the timing of tooth development requires further investigation. The data suggest ethnic differences which could be further explored and may give further insight into factors affecting the timing of development.

Further work could investigate the genetic influences, which may also be characteristic of ethnicity, in the timing of dental development and TMA.

Growth and the timing of puberty is known to vary according to ethnicity with puberty occurring earlier in those of Black African ethnicity compared to those of White ethnicity. There are very few studies which have investigated hormonal influences on tooth development and these could be investigated. Studies could include subjects with conditions affecting the timing of puberty, or of subjects who have been treated with growth hormones or used them or other hormones, for example, as a chosen supplement.

Further investigation could be made into the demographic aspects of treatment need and provision. Awareness of accelerated dental development in Black ethnic groups could improve appropriate referral times and timeliness of specialist treatment provision.

Further work is required to increase understanding and awareness of the complexities and limitations of DAE, rather than its promotion as a more accurate tool than is justifiable.

References

[1] Convention on the Rights of the Child (Article 7). [Internet]. Geneva: Office of the High Commissioner for Human Rights (UN (Human Rights)); 1990 [cited 2020 Jul 30]. Available from: https://www.ohchr.org/en/professionalinterest/pages/crc.aspx

[2] UNICEF. Birth registration. [Internet]. New York: UNICEF; 2017 [updated 2020 June; cited 2020 Jul 29]. Available from: https://data.unicef.org/topic/child-protection/birth-registration/

[3] UNICEF. Crisis of invisibility in Sub-Saharan Africa: Less than 1 in 2 births registered [Internet]. New York: UNICEF; 2017 [updated 2017 Dec 17; cited 2020 May 1]. Available from: https://www.unicef.org/press-releases/crisis-invisibility-sub-saharan-africa-less-1-2-births-registered

[4] Family Planning Association. The law on sex factsheet. [Internet]. Derby, UK: Family Planning Association; 2015 [updated 2015 April; cited 2017 Dec 1]. Available from: www.fpa.org.uk/factsheets/law-on-sex

[5] Jayaraman J, Roberts GJ, Wong HM, McDonald F, King NM. Ages of legal importance: implications in relation to birth registration and age assessment practices. Med Sci Law. 2016; 56(1): 77-82.

[6] Aggrawal A. Estimation of age in the living: in matters civil and criminal. J Anat. 2009; [Internet]. Published online 2009 May 11. Available from: doi:10.1111/j.1469-7580.2009.01048.x

[7] Goodrich J. Age estimation: what are we doing? Oral presentation to American Association of Forensic Sciences Annual Meeting, 2020 Feb 21. Anaheim CA, USA.

[8] World Population Review. Age of majority by State. [Internet]. Walnut, CA, USA: World Population Review; 2020 [Cited 2 May 2020]. Available from: https://worldpopulationreview.com/states/age-of-majority-by-state/

[9] The proceedings of the Old Bailey: London's Central Criminal Court, 1674 to 1913: the trial of Stephen Arrowsmith. [Internet]. London: oldbaileyonline.org. 11 December 1678. [updated 2020 July 29; cited 2020 May 7]. Available from*:* www.oldbaileyonline.org, version 8.0 : "December 1678, trial of Stephen Arrowsmith" (t16781211e-2).

[10] Children and Young Persons Act 1933. [cited 2020 Jul 28]. Available from: https://www.legislation.gov.uk/ukpga/Geo5/23-24/12

[11] UNICEF. Convention on the rights of the child. [Internet]. 30a Great Sutton Street, London EC1 0DU. 20 Nov 1989. Available from: https://downloads.unicef.org.uk/wp-content/uploads/2010/05/UNCRC_PRESS200910web.pdf?_adal_sd=www.unicef.org.uk.1598381757309&_adal_ca=so%3DGoogle%26me%3Dorganic%26ca%3D(not%2520set)%26co%3D(not%2520set)%26ke%3D(not%2520set).1598381757309&_adal_cw=1598381582985.1598381757309&_adal_id=1d9de567-3c2f-4330-9fad-763c576fc05f.1598381583.2.1598381583.1598381583.fcf1e224-8160-4edf-ab5c-172ad2803be5.1598381757309&_ga=2.237343683.237868175.1598381582-676671174.1598381582

[12] The 1951 Refugee Convention. [cited 2020 Jul 28]. Available from: https://www.unhcr.org/uk/1951-refugee-convention.html

[13] United Nations. World refugee day. [Internet]. New York: United Nations; 2020 [Cited 1 May 2020]. Available from: https://www.un.org/en/events/refugeeday/background.shtml

[14] The United Nations High Commissioner for Refugees (UNHCR). Figures at a glance. [Internet]. Geneva: UNHCR; 2020 [Cited 1 May 2020]. Available from: https://www.unhcr.org/uk/figures-at-a-glance.html

[15] UNHCR. Regional summaries: Africa: UNHCR Global Report. [Internet]. 2018 [cited 5 May 2020]. Available from: http://reporting.unhcr.org/sites/default/files/gr2018/pdf/03_Africa.pdf#_ga=2.262156236.1984055702.1588321179-1651805626.1585074017

[16] The Refugee Council. The truth about asylum. [Internet]. London; c2016-20 [updated 2020; cited 21 Dec 2016]. Available from: http://www.refugeecouncil.org.uk/policy_research/the_truth_about_asylum/the_facts_about_asylum

[17] Home Office. Children's Asylum Claims Version 2.0. published for Home Office staff. [Internet]. London; 09 October 2017. [cited 2017 Oct 28]. Available from: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/650514/children_s-asylum-claims-v2_0.pdf

[18] The Children Act 1989 Section 20. [cited 2017 Oct 28] Available from: https://www.legislation.gov.uk/ukpga/1989/41

[19] Roberts GJ, Lucas VS. Ethical Age Assessment. [Internet]. Br Dent J. 2009. Available from: https://www.nature.com/articles/sj.bdj.2009.821

[20] Tosam MJ. The ethical and social implications of age-cheating in Africa. Int J Philos. 2015; 3(1): 1-11.

[21] Mayer F, Arent T, Geserick G, Grundmann C, Lockemann U, Riepert T, Schmeling A, Ritz-Timme. Age estimation based on pictures and videos presumably showing child or youth pornography. Int J Legal Med. 2014; 128: 649-652.

[22] De Angelis D, Gibelli D, Fabbri P, Cattaneo C. Dental age estimation helps create a new identity. Am J Forensic Med Pathol. 2015; 36(3): 219-20.

[23] Save The Children. Young refugees: working with unaccompanied asylum-seeking children at ports. [Internet]. 2002 [Cited 2017 Oct 28]. Available from: http://www.unhcr.org/50a5121b9.pdf

[24] Wilner P, Rowe G. Alcohol servers' estimates of young people's ages. Drugs: Educ Prev Polic. 2001; 8: 375-383.

[25] Clifford CWG, Watson TL, White D. Two sources of bias explain errors in facial age estimation. [Internet]. R Soc Open Sci. 2018; 5:180841 Available from: http://dx.doi.org/10.1098/rsoc.180841

[26] Rosenbloom AL, Tanner JM. Misuse of the Tanner puberty stages to estimate chronologic age. Pediatrics. 1998; 102: 1494.

[27] Marshall WA, Tanner JM. Variations in pattern of pubertal changes in girls. Arch Dis Child. 1969; 44: 291-303.

[28] Greulich WW, Pyle SI. Radiographic atlas of skeletal development of the hand and wrist. Stanford: Stanford University Press; 1959.

[29] Logan WHG, Kronfeld R. Development of the human jaws and surrounding structures from birth to the age of fifteen years. J Am Dent Assoc. 1933; 20: 379-427.

[30] Liversidge HM, Herdeg B, Rosing FW. Dental age estimation of non-adults: a review of methods and principles. In: Alt WK, Rosing FW, Teschler-Nicola M, editors. Dental anthropology: fundamentals, limits and prospects. New York: Springer; 1998. p. 419-442.

[31] Thompson T, Black S. Forensic human identification an introduction. Boca Raton, Fl, USA: CRC Press; 2007. p.199-228.

[32] Demirjian A, Buschang PH, Tanguay R, Patterson DK. Interrelationships among measures of somatic, skeletal, dental, and sexual maturity. Am J Orthod. 1985; 88**:** 433-8.

[33] Schaefer M, Black S, Scheuer L. Juvenile osteology: a laboratory and field manual. Burlington MA, USA: Academic Press Elsevier; 2009.

[34] Thompson T, Black S. Forensic human identification: an introduction. Boca Raton, Fl, USA. CRC Press. 2007. p.199-219.

[35] Personal communication (2020 Jul 17) with Gillian Fowler, Lead Consultant in Forensic Anthropology and Archaeology, Alecto Forensic Services.

[36] Schmeling A, Reisinger W, Loreck D, Vendura K, Markus W, Geserick G. Effects of ethnicity on skeletal maturation: consequences for forensic age estimations. Int J Legal Med. 2000; 253-258.

[37] Schmeling A, Garamendi PM, Prieto JL, Landa MI. Forensic age estimation in unaccompanied minors and young living adults. In: Vieira DN, editor. Forensic medicine - from old problems to new challenges. London: InTech Open; 2011. p.77-120.

[38] Cole TJ, Rousham EK, Hawley NL, Cameron N, Norris SA, Pettifor JM. Ethnic and sex differences in skeletal maturation among the Birth to Twenty cohort in South Africa. Arch Dis Child. 2015; 100(2): 138-143.

[39] Cameriere R. AgEstimation project: Cameriere's methods for age estimation. 2008. Macerata, Italy. Eum editizioni universita di macerata. p.12

[40] Gilsanz V, Ratib O. Hand bone age: a digital atlas of skeletal maturity. 2005. Berlin. Springer; and available as an eBook.

[41] Cameriere R, Ferrante L, Mirtella D, Cingolani M. Carpals and epiphyses of radius and ulna as age indicators. Int J Legal Med. 2006; 120(3): 143-146.

[42] Tanner JM, Whitehouse RJ, Healy MRJ. A new system for estimating skeletal maturity from the hand and wrist with standards derived from a study of 2,600 healthy British children (Part II): the scoring system. 1962. Paris: International Child Centre; p.92.

[43] Tanner JM, Whitehouse RH, Cameron N, Marshall WA, Healy MJR, Goldstein H. Assessment of skeletal maturity and prediction of adult height. London: Academic Press; 1983. p.93.

[44] Tanner JM, Healy MRJ, Goldstein H, Cameron N. Assessment of skeletal maturity and prediction of adult height (TW3). 3rd edition. London: Saunders Ltd; 2001.

[45] Franklin D, Flavel A, Noble J, Swift L, Karkhanis S. Forensic age estimation in living individuals: methodological considerations in the context of medico-legal practice. Research and Reports in Forensic Medical Science. 2015; 5: 53-66.

[46] Schmeling A, Reisinger W, Geserick G, Olze A. Age estimation of unaccompanied minors. Part 1. General considerations. Forensic Sci Int. 2006; 15 159 Suppl 1:S61- S64.

[47] Chaumoitre B, Saliba-Serre P, Adalian M, Signoli G, Leonetti M, Panuel K. Forensic use of the Greulich and Pyle atlas: prediction intervals and relevance. Eur Radiol. 2017; 27:1032–1043.

[48] Thiemann HH, Nitz I. Röntgenatlas der normalen hand im kindesalter. Leipzig: Thieme; 1991.

[49] Gilsanz V, Ratib O. Hand bone age: a digital atlas of skeletal maturity. 2nd ed. Berlin: Springer-Verlag; 2011.

[50] Schmeling A, Grundman C, Fuhrman A, Kaatsch HJ, Knell B, Ramstahler F, Reisinger W, Riepert T, Ritz-Timme S, Rosing FW, Rotzscher K, Geserick G. Criteria for age estimation in living individuals**.** Int J Legal Med. 2008; 122 (6): 457-460.

[51] Nuzzolese E, di Vella G. Forensic dental investigations and age assessment of asylum seekers. Int Dent J. 2008; 58: 122-126.

[52] Pinchi V. Migratory flows across Mediterranean: new challenges for forensic sciences. Oral Presentation at IOFOS Conference, Leuven, Belgium, 2017 Sept 14.

[53] Richter S. Age estimation of unaccompanied minors in the Nordic countries. Oral Presentation at IOFOS Conference, Leuven, Belgium, 2017 Sept 15.

[54] Schmidt S, Vieth V, Timme M, Dvorak J, Schmeling A. Examination of ossification of the distal radial epiphysis using magnetic resonance imaging. New insights for age estimation in young footballers in FIFA tournaments. Sci Justice 2015; 55: 139-144.

[55] Schmidt S, Ottow C, Pfeiffer H, Heindl W, Vieth V, Schmeling A, Schulz R. Magnetic resonance imaging-based evaluation of ossification of the medial clavicular epiphysis in forensic age assessment. Int J Legal Med. 2017; 131: 1665.

[56] Vieth V, Schulz R, Brinkmeier P, Dvorak J, Schmeling A. Age estimation in U-20 football players using 3.0 tesla MRI of the clavicle. Forensic Sci Int. 2014; 241: 118-122.

[57] Norwegian Institute of Public Health. Ding KY, Rolseth V, Dahlberg PS, Mosdøl A, Straumann GH, Bleka Ø, Vist GE. Report: age estimation by ossification stages of the medial clavicular epiphysis: a systematic review (Estimering av alder ved hjelp av utviklingsstadier av det mediale kragebeinet: en systematisk oversikt). [Internet]. 2018 [cited 2020 May 28]. Available from: https://pdfs.semanticscholar.org/c2ee/696144f7befe6d8ad30da59c91e6858a756b.pdf?_ga=2.58220394.1337223258.1596048900-2071091692.1596048900

[58] Hermetet C, Saint-Martin P, Gambier A, Ribier L, Sautenet B, Rérolle C. Forensic age estimation using computed tomography of the medial clavicular epiphysis: a systematic review. Int J Legal Med. 2018;132(5): 1415-1425.

[59] Franklin D, Flavel A, Noble J, Swift L, Karkhanis S. Forensic age estimation in living individuals: methodological considerations in the context of medico-legal practice. Research and Reports in Forensic Medical Science. 2015; 5:53-66

[60] Mörnstad H. Age estimations of unaccompanied minors in Sweden 2015-2016. Oral Presentation at IOFOS Conference, Leuven, Belgium, 2017 Sept 15.

[61] Malmqvist E, Furberg E, Sandman L. Ethical aspects of medical age assessment in the asylum process: a Swedish perspective. Int J Legal Med. 2018; 132(3): 815-823.

[62] Cameriere R, Giuliodori A, Zampi M, Galic I, Cingolani M, Pagliara F, Ferrante L. Age estimation in children and young adolescents for forensic purposes using fourth cervical vertebra (C4). Int J Legal Med. 2015; 129: 347-355.

[63] Manica S. Wong FSL, Davis G, Liversidge HM. Estimating age using permanent molars and third cervical vertebrae shape with a novel semi-automated method. J Forensic Leg Med. 2018; 58:140-144.

[64] Berkowitz BKB, Holland GR, Moxham BJ. Oral Anatomy, Histology and Embryology. 4th Edition. Edinburgh: Mosby Elsevier; 2009. p.365.

[65] Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Hum Biol. 1973; 45: 211-27.

[66] Nelson SJ, Ash MM. Wheeler's Dental Anatomy, Physiology, and Occlusion. 9th Edition. St Louis, Missouri: Saunders Elsevier; 2010.

[67] Grøn A-M. Prediction of tooth emergence. J Dent Res. 1962; 41: 573-584.

[68] Demirjian A, Levesque G-Y. Sexual differences in dental development and prediction of emergence. J Dent Res. 1980; 59: 1110-1122.

[69] Gleiser I, Hunt EE. The permanent mandibular first molar: its calcification, eruption and decay. Am J Phys Anthropol. 1955; 13: 253-283.

[70] Banks HV. Incidence of third molar development. Angle Orthod. 1934; 4(3): 223-233.

[71] Schour L, Massler M. The development of the human dentition. J Am Dent Assoc. 1941; 28: 1153–1160.

[72] AlQahtani SJ, Hector MP, Liversidge HM. Brief communication: the London atlas of human tooth development and eruption. Am J Phys Anthropol. 2010; 142: 481-490.

[73] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.22-23.

[74] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.96.

[75] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.98.

[76] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.134-136.

[77] Seow WK, Wright JT. Diagnosis and management of defects in enamel development. In: Wright JT, editor. Craniofacial and dental developmental defects, diagnosis and management. Switzerland: Springer International Publishing; 2015. p.81-96.

[78] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.114.

[79] Kühnisch J, Thiering E, Kratzsch J, Heinrich-Weltzien R, Hickel R, Heinrich J, Elevated serum 25(OH)-vitamin D levels are negatively correlated with molar-incisor hypomineralization. J Dent Res. 2015; 94(2): 381-387.

[80] Koong B. Atlas of oral and maxillofacial radiology. Chichester: John Wiley & Sons, UK; 2017. p.2095-2169.

[81] Nazzal H, Duggal MS. Defects in dentin development. In: Wright JT, editor. Craniofacial and dental developmental defects, diagnosis and management. Switzerland: Springer International Publishing; 2015. p.97-111.

[82] Holt R, Roberts G, Scully C. Oral health and disease. BMJ. 2000; 320:1652-1655.

[83] Kosowicz J, Rzymski K. Abnormalities of tooth development in pituitary dwarfism. Oral Surg Oral Med Oral Path. 1977; 44(6): 853-863.

[84] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.29.

[85] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.30.

[86] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.32.

[87] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.63.

[88] Bailleul-Forestier I, Berdal A, Vinekier F, de Ravel T, Fryns JP, Verloes A. The genetic basis of inherited anomalies of the teeth Part 2: syndromes with significant dental involvement. Eur J Med Genet. 2008; 51: 383-408.

[89] Berry AC. Anthropological and family studies on minor variants of the dental crown. In: Butler PM, Joysey KA, editors. Development, function and evolution of the teeth. London; Academic Press. 1978. p.81-98.

[90] Vastardis H. The genetics of human tooth agenesis: new discoveries for understanding dental anomalies. Am J Orthod Dentofacial Orthop. 2000; 117(6): 650-6.

[91] Haga S, Nakaoka H, Yamaguchi T, Yamamoto K, Kim, Y-I, Samoto H, Ohno T, Katayama K, Ishida H, Park S-B, Kimura R, Maki K, Inoue I. A genome-wide association study of third molar agenesis in Japanese and Korean populations. J Hum Genet. 2013; 58: 799-803.

[92] Swee J, Silvestri AR Jr, Finkelman MD, Rich AP, Alexander SA, Loo CY. Inferior alveolar nerve block and third-molar agenesis: a retrospective clinical study. J Am Dent Assoc. 2013; 144: 389-395.

[93] Tagger E, Tagger M, Sarnat H, Mass E. Periodontal ligament injection in the dog primary dentition: spread of local anaesthetic solution. Int J Paediatr Dent. 1994; 4:159-166.

[94] Zhuang H, Hu D, Singer D, Walker JV, Nisr RB, Tieu K, Ali K, Tredwin C, Luo S, Ardu S, Hu B. Local anesthetics induce autophagy in young permanent tooth pulp cells. Cell Death Discov. 2015; 1; 15024.

[95] Soxman JA, Wunsch PB, Haberland CM. Anomalies of the developing dentition: a clinical guide to diagnosis and management. Switzerland: Springer Nature; 2019. p.40.

[96] Goblirsch AW. A study of third molar teeth J Am Dent Assoc 1930; 17: 1849-1854 cited in Nanda RS. Agenesis of the third molar in man. Am J Orthodontics. 1954; 40: 698-706.

[97] Hellman M. Our third molar teeth, their eruption, presence and absence. Dental Cosmos. 1936; 78: 750-762.

[98] De Terra M. Beiträge zu einer Odontographie der Menschenrasses. Freise. 1905; 226-234 cited in Nanda RS. Agenesis of the third molar in man. Am J Orthod. 1954; 40: 698-706.

[99] Mori T. On the ages of eruption of third molars and the stages of calcification of their roots. J Nippon Dent A (Nippon Shikwa Gk Z) 1931; 24: 80-116 cited in Nanda RS. Agenesis of the third molar in man. Am J Orthod. 1954; 40: 698-706.

[100] Nanda RS. Agenesis of the third molar in man. Am J Orthodontics. 1954; 40: 698-706.

[101] Rozkovcova E, Markova M, Dolejsi J. Studies on agenesis of third molars amongst populations of different origin. Sb Lek. 1999; 100(2): 71-84.

[102] Thomsen SO. Missing teeth with special reference to the population of Tristan da Cunha. Am J Phys Anthropol. 1952; 10: 155-167 cited in Garn SM, Lewis AB. The relationship between third molar agenesis and reduction in tooth number. J Dent Res. 1962*;* 42: 1344-1363.

[103] Lavelle CL, Ashton EH, Flinn RM. Cusp pattern, tooth size, and third molar agenesis in the human mandibular dentition. Arch Oral Biol. 1970; 15: 227-37.

[104] Lavelle CLB, Moore WJ. The incidence of agenesis and polygenesis in the primate dentition. Am J Phys Anthropol. 1973; 38: 671-680.

[105] Harris EF, Clark LL. Hypodontia: an epidemiologic study of American black and white people. Am J Orthod Dentofacial Orthop. 2008; 134(6):761-767.

[106] Kruger E, Thomson WM, Kontthasinghe P. Third molar outcomes from age 18 to 26: findings from a population-based New Zealand longitudinal study. Oral Surg Oral Med Oral Pathol Oral Radiol Endod 2001; 92: 150-155.

[107] Barka G, Tretiakov G, Theodosiou T, Ionnadou-Marathiotou I. Presence of third molars in orthodontic patients from Northern Greece. Int J Gen Med. 2012; 5: 441-447.

[108] Kazanci F, Celikoglu M, Miloglu O, Oktay H. Third-molar ageness among patients fro the East Anatolian region of Turkey. J Contemp Dent Prac. 2010; 11(4): E033-E040.

[109] Celikoglu M, Miloglu O, Kazanci F. Frequency of agenesis, impaction, angulation and related pathologic changes of third molar teeth in orthodontic patients. J Oral Maxillofac Surg. 2010; 68: 990-5.

[110] Carter S, Worthington S. Morphologic and demographic predictors of third molar agenesis: a systematic review and meta-analysis. J Dent Res. 2015; 94(7): 886-894.

[111] Forjani A, Sarri J, Hector MP, Liversidge HM (2008) The pattern of third molar agenesis. Barts and The London School of Medicine and Dentistry, United Kingdom. Pan European Federation of the International Association for Dental Research 2008 Conference. [Cited 2020 Aug 20]. Available from: https://iadr.abstractarchives.com/abstract/pef08-111423/the-pattern-of-third-molar-agenesis

[112] Schultz A. Inherited reductions in the dentition of man. Hum Biol. 1934; 6: 627-631.

[113] Garn SM, Lewis AB. The relationship between third molar agenesis and reduction in tooth number. J Dent Res. 1962; 42: 1344-1363.

[114] Celikoglu M, Bayram M, Nur M. Patterns of third molar agenesis and associated dental anomalies in an orthodontic population. Am J Orthod Dentofacial Orthop. 2011; 140: 856-60.

[115] Abu Alhaja ES, Derbash AA, Al-Khateeb SN. Dental age assessment in Caucasian subjects with third molar agenesis. Australian Orthodontic Journal. 2017; 33(1):35-39.

[116] Uslenghi S, Liversidge HM, Wong FSL. A radiographic study of tooth development in hypodontia. Arch Oral Biol. 2006; 51:129-133.

[117] Lebbe A, Cadenas de Llano-Perula M, Thevissen P, Verdonck A, Fieuws S, Willems G. Dental development in patients with agenesis. Int J Legal Med. 2017; 131: 537-546.

[118] Lomholt JF, Russell BG, Stoltze K, Kjaer I. Third molar agenesis in Down syndrome. Acta Odontol Scand**.** 2002; 60(3): 151-154.

[119] Müller N. Dental age determination based on the assessment of third molar development. Inaugural dissertation, Medizinische Fakultät der Friedrich, Alexander-Universität Erlangen, Nürnberg. 1990, cited in Willershausen I, Försch M, Willershausen B. Possibilities of dental age assessment in permanent teeth: a review. Dentistry. [Internet] 2012. S1:001. [Cited 2020 Jul 27]. Available from: doi:10.4172/2161-1122.S1-001.

[120] Saunders E. The teeth a test of age. Lancet. 1838; 30(774): 492-496.

[121] Thomson AT. Lecture 7. Lancet. 1836-7; 9(i). In: Wellcome Collection. Saunders E. The teeth a test of age, considered with reference to the factory children: addressed to Members of Both the Houses of Parliament. [Internet]. London: H. Renshaw; 1837. [Cited 2020 Jul 27]. Available from: https://wellcomecollection.org/works/fmzgc3ub/items?canvas=13&langCode=eng&sierraId=b21980895

[122] Saunders E. The teeth a test of age considered with reference to the factory children, addressed to Members of Both the Houses of Parliament. [Internet]. London: H. Renshaw; 1837. [Cited 2020 Jul 27]. Available online from:

https://wellcomecollection.org/works/fmzgc3ub/items?canvas=13&langCode=eng&sierraId=b21980895 .

[123] Fanning E. Third molar emergence in Bostonians. Am J Phys Anthropol. 1962; 20: 339-345.

[124] Schour I, Massler M. Studies in tooth development: the growth pattern of human teeth. J Am Dent Assoc. 1940; 27: 1778-1792, 1918-1931.

[125] Schour I, Massler M. The development of the human dentition. 2nd edition. Chicago: American Dental Association; 1944.

[126] Uberlaker DH. Human skeletal remains: excavation, analysis, interpretation. Chicago: Aldine Publishing Co. Inc; 1978.

[127] Hunt EE, Gleiser I. The estimation of age and sex of preadolescent children from bones and teeth. Am J Phys Anthropol. 1955; 13: 479-487.

[128] Köhler S, Schmelze R, Loitz C, Püschel K. Development of wisdom teeth as a criterion of age determination. Ann Anat. 1994; 176: 339-345.

[129] Nolla CM. The development of the permanent teeth. J Dent Child. 1960; 27: 254-266.

[130] Haavikko K. The formation and the alveolar and clinical eruption of the permanent teeth: an orthopantomographic study. Thesis. Helsinki; Suom. Hammaslaak: 1966.

[131] Haavikko K. Tooth formation age estimated on a few selected teeth: a simple method for clinical use. Proc Finn Dent Soc. 1974; 70(1): 15-19.

[132] Nortje CA. The permanent mandibular third molar: its value in age determination. J Forensic odontostomatol. 1983; 1(1): 27-31.

[133] Harris MJ, Nortje CJ. The mesial root of the third mandibular molar: a possible indicator of age. J Forensic odontostomatol. 1984; 2(2): 39-43.

[134] Demirjian A, Goldstein H. New systems for dental maturity based on seven and four teeth. Ann Hum Biol. 1976; 3: 411-421.

[135] Willems G, Thevissen PW, Belmans A, Liversidge HM. Willems II: Non-gender-specific dental maturity scores. Forensic Sci Int. 2010; 201: 84-85.

[136] Kvaal SI, Kolltveit KM, Thomsen IO, Solheim T. Age estimation of adults from dental radiographs. Forensic Sci Int. 1995; 74: 175-185.

[137] Cameriere R, Ferrante L, Belcastro MG, Bonfiglioli B, Rastelli E, Cingolani M. Age estimation by pulp/tooth ratio in canines by peri-apical X-rays. J Forensic Sci. 2007; 52(1): 166-170.

[138] Cameriere R, Ferrante L, Cingolani M. Age estimation in children by measurement of open apices in teeth. Int J Legal Med. 2006; 120: 49-52.

[139] Guo Y, Olze A, Ottow C, Schmidt S, Schulz R, Heindl W, Pfeiffer H, Vieth V, Schmeling A. Dental age estimation in living individuals using 3.0 T MRI of lower third molars. Int J Legal Med. 2015; 129: 1265-1270.

[140] De Tobel J, Phylpo I, Fieuws S, Politis C, Verstraete K, Thevissen P. Forensic age estimation based on development of third molars: a staging technique for magnetic resonance imaging. J Forensic Odontostomatol. 2017; 35(2): 125-145.

[141] Pérez-Mongiovi D, Teixeira A, Caldas IM. The radiographic visibility of the root pulp of the third molar as an age marker. Forensic Sci Med Pathol. 2015; 11: 339-344.

[142] Gustafson G. Age determination on teeth. J Am Dent Assoc. 1950; 41: 45-54.

[143] Bang G, Ramm E. Determination of age in humans from root dentin transparency. Acta Odonto Scand. 1970; 28(1): 3-35.

[144] Thomas GJ, Whittaker DK, Embery G. A comparative study of translucent apical dentine in vital and non-vital human teeth. Archs Oral Biol. 1994; 39(1): 29-34.

[145] Acharya A. A new digital approach for measuring dentin translucency in forensic age estimation. Am J Forensic Med Pathol. 2010; 31(2): 133-137.

[146] Aggrawal P, Saxena S, Bansal P. Incremental lines in root cementum of human teeth: an approach to their role in age estimation using polarizing microscopy. Indian J Dent Res. 2008; 19(3): 326-330.

[147] Antoine D, Hillson S, Dean MC. The developmental clock of dental enamel: a test for the periodicity of prism cross-striations in modern humans and an evaluation of the most likely sources of error in histological studies of this kind. J Anat. 2009; 214: 45-55.

[148] Whittaker DK, Richards D. Scanning electron microscopy of the neonatal line in human enamel. Arch Oral Biol. 1978; 23(1): 45-50.

[149] Helfman PM, Bada JL. Aspartic acid racemization in tooth enamel from living humans. Proc Nat Acad Sci USA 1975; 72(8): 2891-2894.

[150] Alkass K, Buchholz BA, Ohtani S, Yamamotot T, Druid H, Spalding KL. Age estimation in forensic sciences application of combined aspartic acid racemization and radiocarbon analysis. Mol Cell Proteomics. 2010; 9: 1022-1030.

[151] Waite ER, Collins MJ, Ritz-Timme S, Schutz H-W, Cattaneo C, Borrman HIM. A review of the methodological aspects of aspartic acid racemization analysis for use in forensic science. Forensic Sci Int. 1999; 103:113-124.

[152] Alkass K, Buchholz BA, Druid H, Spalding KL. Analysis of 14C and 13C in teeth provides precise birth dating and clues to geographical origin. Forensic Sci Int. 2011; 209(1-3): 34-41.

[153] Griffin R, Moody H, Penkman K, Fagan M, Curtis N, Collins M. A new approach to amino acid racemization in enamel: testing of a less destructive sampling methodology. Forensic Sci Int. 2008; 53(4): 910-6.

[154] Roberts GJ, Petrie A. Dental age assessment (DAA): of children and emerging adults: a practical guide. In: Daskalaki A, editor. Digital forensics for the health sciences: applications in practice and research. Hershey PA, USA: Medical Information Science Reference IGI Global; 2011. p.226-279.

[155] Cameriere R, Ferrante L, De Angelis D, Scarpino F, Galli F. The comparison between measurement of open apices of third molars and Demirjian stages to test chronological age of over 18 year olds in living subjects. Int J Legal Med. 2008; 122: 493-497.

[156] Roberts GJ, Parekh S, Petrie A, Lucas VS. Dental age assessment (DAA): a simple method for children and emerging adults. Br Dent J. 2008; 204: E7.

[157] Roberts G, Lucas V, McDonald F. Age estimation in the living: dental age estimation - theory and practice. In: Bayard R, Payne-James J, editors in chief. Encyclopedia of forensic and legal medicine. 2nd edition. Elsevier; 2016. p.41-69.

[158] Roberts G, Lucas VS, McDonald F, Camilleri S, Jayaraman J, Davies D, Moze K. In our opinion. Br Dent J. 2017; 222 12: 918-921.

[159] Mitchell JC, Roberts GJ, Donaldson ANA, Lucas VS. Dental Age Assessment (DAA): Reference data for British Caucasians at the 16 year threshold. Forensic Sci Int. 2009; 189:19-23.

[160] Blankenship JA, Mincer HH, Anderson KM, Woods MA, Burton EL. Third molar development in the estimation of chronologic age in American Blacks as compared with Whites. J Forensic Sci. 2007; 52: 428-83.

[161] Moorrees CF, Fanning EA, Hunt EE Jr. Age variation of formation stages for ten permanent teeth. J Dent Res. 1963; 42:1490-1502.

[162] Levesque GY, Demirjian A, Tanguay R. Sexual dimorphism in the development, emergence, and agenesis of the mandibular third molar. J Dent Res. 1981; 60: 1735-41.

[163] Liversidge HM, Peariasamy K, Folayan MO, Adeniyi AA, Ngom PI, Mikami Y, Shimada Y, Kuroe K, Tvete IF, Kvaal SI. A radiographic study of the mandibular third molar root development in different ethnic groups. J Forensic Odontostomatol. 2017; 35(2): 97-108.

[164] Lewis JM, Senn DR. Dental age estimation using third molar development: a review of principles, methods, and population studies used in the United States. Forensic Sci Int. 2010; 201: 79-83.

[165] American Board of Forensic Odontology Inc. (ABFO). Diplomates Reference Manual. [Internet]. March 2017 Edition. USA. 2017. p124. [cited 2020 August 20]. Available from http://abfo.org/wp-content/uploads/2012/08/ABFO-DRM-Section-4-Standards-Guidelines-Mar-2017.pdf
and personal communication with Derek Draft, creator of Quicksheets™ at AAFS 20th Annual Meeting, Anaheim CA, USA, February 2020.

[166] Draft D, Lucas VS, McDonald F, Andiappan M, Roberts G. Expressing uncertainty in dental age estimation: a comparison between two methods of calculating the "average" standard deviation. J Forensic Sci. 2019; 64: 1506-1509.

[167] Roberts GJ, Petrie A, with contributions by Boonpitaksahit T, Parekh S, Percival T, Mitchell J, Yadava M, Donaldson N, Moze K, Lucas VS. Dental Age Assessment (DAA) of children and emerging adults: a practical guide. Department of Paediatric Dentistry, King's College Hospital, Bessemer Road, London SE5 9RS. Prof. Graham Roberts. 2009.

[168] Roberts GJ, McDonald F, Neil M, Lucas VS. The weighted average method "WAM" for dental age estimation: a simpler method for children at the 10 year threshold. J Forensic Leg Med. 2014; 26: 56-60.

[169] Willems G, Van Olmen A, Splessens B, Carels C. Dental age estimation in Belgian children: Demirjian's technique revisited. J Forensic Sci. 2001; 46(4): 893-895.

[170] Sehrawat JS, Singh M. Willems method of dental age estimation in children: a systematic review and meta-analysis. J Forensic Leg Med. 2017; 52:122-129.

[171] Willems G, Lee SS, Uys A, Bernitz H, Cadenas de Llano-Pérula MC, Fieuws S, Thevissen P. Age estimation based on Willems method versus new country-specific method in South African black children. Int J Legal Med. 2017; 132(2): 599-607.

[172] Olze A, Solheim T, Schulz R, Kupfer M, Schmeling A. Evaluation of the radiographic visibility of the root pulp in the lower third molars for the purpose of forensic age estimation in living individuals. Int J Legal Med. 2010; 124:183-186.

[173] Olze A, Solheim T, Schulz R, Kupfer M, Pfeiffer H, Schmeling A. Assessment of the radiographic visibility of the periodontal ligament in the lower third molars for the purpose of forensic age estimation in living individuals. Int J Legal Med. 2010; 124: 445-448.

[174] Lucas VS, McDonald F, Andiappan M, Roberts G. Dental age estimation - root pulp visibility (RPV) patterns: a reliable mandibular maturity marker at the 18 year threshold. Forensic Sci Int. 2017; 270: 98-102.

[175] Lucas VS, McDonald F, Andiappan M, Roberts G. Dental age estimation: periodontal ligament visibility (PLV) - pattern recognition of a mandibular maturity marker related to the lower left third molar at the 18-year threshold. Int J Legal Med. 2017; 131(3): 797-801.

[176] Lucas VS, McDonald F, Andiappan M, Roberts G. Periodontal ligament visibility (PLV): validation of PLV to determine adult status. J Forensic Odontostomatol. 2017. 35(2): 95-101.

[177] Roberts GJ, Lucas VS, Andiappan M, McDonald F. Dental age estimation: pattern recognition of root canal widths of mandibular molars. A novel mandibular maturity marker at the 18-year threshold. J Forensic Sci. 2017; 62(2): 351-354.

[178] Timme M, Timme WH, Olze A, Ottow C, Ribbecke S, Pfeiffer H, Dettmeyer R, Schmeling A. The chronology of the radiographic visibility of the periodontal ligament and the root pulp in the lower third molars. Science and Justice. 2017 **57**:257-261.

[179] Lucas VS, McDonald F, Andiappan M, Roberts G,. Dental age estimation: periodontal ligament visibility (PLV) – pattern recognition of a conclusive mandibular maturity marker related to the lower left third molar at the 18-year threshold. Int J Legal Med. 2017; 131(3):797-801.

[180] European Council on refugees and exiles (ECRU) asylum information database (AIDA). Detriment of the doubt: age assessment of unaccompanied asylum-seeking children. Legal briefing No.5 December 2015 citing Directive 2013/32/EU of the European Parliament and of the Council of 26 June 2013 on common procedures for granting and withdrawing international protection (recast), OJ 2013 L180/60, Article 25(5) [Internet]. 2015 [cited 2018 Jan 27]. Available from: http://www.asylumlawdatabase.eu/sites/www.asylumlawdatabase.eu/files/aldfiles/AIDA%20Brief%205_AgeAssessment.pdf

[181] Personal communication with Professor Graham Roberts, King's College Dental Institute, 2 December 2016.

[182] Refugee Council. Court confirms age policy is unlawful. [Internet]. 2017. [Cited 8 May 2020]. Available from: https://www.refugeecouncil.org.uk/latest/news/4866_court_confirms_government_s_age_policy_is_unlawful/

[183] *R (A-M AA (Sudan)) v The Secretary of State for the Home Department* [2017] EWCA Civ 138

[184] Home Office. Assessing Age 3.0 published for Home Office staff. [Internet]. London; 2020. [cited 2020 May 5]. Available from: https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/804760/Assessing-age-asylum-instruction-v3.0ext.pdf

[185] UNHCR. Convention and protocol relating to the status of refugees (1951, 1967). [Internet] UNHCR Communications and Public Information Service, Geneva. [Cited 12 Nov 2017]. Available from: http://www.unhcr.org/uk/3b66c2aa10

[186] Home Office. National statistics data. [Internet]. 2020. [Cited 12 May 2020]. Available from: https://www.gov.uk/government/publications/immigration-statistics-year-ending-march-2018/how-many-people-do-we-grant-asylum-or-protection-to#unaccompanied-asylum-seeking-children)

[187] Home Office. National statistics data asylum and resettlement summary tables, year ending June 2019 second edition. [Internet]. 2020. [Cited 12 May 2020]. Available from: www.gov.uk/government/statistical-data-tables-year-ending-june-2019

[188] [14] *R (Bomba) v London Borough of Merton* [2003] EWHC 1689 (Admin.) [Internet]. [Cited 2017 oct 28]. Available from: http://www.asylumlawdatabase.eu/sites/asylumlawdatabase.eu/files/aldfiles/UK_060%20Judgment.pdf

[189] The Association of Directors of Children's Services (ADCS). Age Assessment Guidance – guidance to assist social workers and their managers in undertaking age assessments in England. [Internet]. October 2015. [Cited 27 Jan 2018]. Available from: http://adcs.org.uk/assets/documentation/Age_Assessment_Guidance_2015_Final.pdf

[190] *Supreme Court judgement in R (on the application of A) v Croydon London Borough Council*. [2009]. [Cited 27 Jan 2018]. Available from: https:/www.supremecourt.uk/cases/uksc-2009-0106.html

[191] *R (on the application of ZM and SK) v The London Borough of Croydon (Dental age assessment)* [2016] UKUT 559 (IAC). [Cited 27 Jan 2018]. Available from: http://www.bailii.org/uk/cases/UKUT/IAC/2016/559.html

[192] Local Government and Social Care Ombudsman. Report on an investigation into complaint no. 08 005 858 against Liverpool City Council. [Internet]. 24 March 2010. [Cited 28 Apr 2020]. Available from: https://www.lgo.org.uk/decisions/children-s-care-services/other/08-005-858

[193] European Asylum Support Office (EASO). EASO Practical guide series: practical guide on age assessment. 2nd edition. [Internet]. March 2018 [cited on 2020 May 7]

https://www.easo.europa.eu/sites/default/files/easo-practical-guide-on-age-assesment-v3-2018.pdf

[194] *R (on the application of A) v Croydon London Borough Council* [2009] 1 WLR 2557.

[195] BBC News. Sweden child migrant tests 'reveal many adults' [Internet]. 2017 Dec 5. [Cited 4 Feb 2021]. Available from: https://www.bbc.co.uk/news/world-europe-42234585

[196] BBC News. How do you verify the age of asylum seekers? [Internet]. 2016 Oct 19. [Cited 4 Feb 2021]. Available from: https://www.bbc.co.uk/news/uk-37687916

[197] Cole TJ. The evidential value of developmental age imaging for assessing age of majority. Ann Hum Biol. 2015; 42(4): 379-388.

[198] Bulman M. Can dental X-rays determine a child's age? The Independent. 2016 Oct 19. [Internet] [Cited 4 Feb 2021]. Available from: https://www.independent.co.uk/news/uk/home-news/child-refugees-age-can-dental-checks-determine-how-old-someone-calais-jungle-a7369531.html

[199] Larsen ST, Arge S, Lynnerup N. The Danish approach to forensic age estimation in the living: how, how many and what's new?: a review of cases performed in 2012. Ann Hum Biol. 2015; 42:4: 342-347.

[200] Rosenbloom A. Inaccuracy of age assessment from images of post pubescent subjects in cases of alleged child pornography. [Internet]. Int J Legal Med. Published online 8 September 2012. doi: 10.1007/s00414-012-0765-8

[201] Rosenbloom AL, Tanner JM. Misuse of the Tanner puberty stages to estimate chronologic age. Pediatrics. 1998; 102:1494.

[202] Garn SM, Lewis AB, Kerewsky RS. Genetic, nutritional, and maturational correlates of dental development. J Dent Res. 1965;(Suppl.): 228-242.

[203] Cameriere R, Flores-Mir C, Mauricio F, Ferrante L. Effects of nutrition on timing of mineralization in teeth in a Peruvian sample by the Cameriere and Demirjian methods. Ann Hum Biol. 2007; 34: 547-556.

[204] Garn S. M., Lewis A. B. and Blizzard R. M. Endocrine factors in dental development. J Dent Res. 1965; 44 (Suppl.): 243-258.

[205] Taylor J, Blenkin M. Age evaluation and odontology in the living. In: Black S, Aggrawal A, Payne-James J, editors. Age estimation in the living: The practitioner's guide. New Delhi: Wiley-Blackwell; 2010. p. 178.

[206] Esan TA, Yengopal V, Schepartz LA. The Demirjian versus the Willems method for dental age estimation in different populations: a meta-analysis of published studies PloS one. 2017;
12: e0186682. Available from: doi:10.1371/journal.pone.0186682.

[207] Harris EF. Mineralization of the mandibular third molar: a study of American Blacks and Whites. Am J Phys Anthropol. 2007; 132: 98-109.

[208] Lewis A, Garn S. The relationship between tooth formation and other maturational factors. Angle Orthod. 1960; 30: 70-77.

[209] Nadler GL. Earlier dental maturation: fact or fiction? Angle Orthod. 1998; 68(6): 535-538.

[210] Sun SS, Schubert CM, Chumlea WC, Roche AF, Kulin HE, Lee PA, Himes JH, Ryan AS. National estimates of the timing of sexual maturation and racial differences among US children. Pediatrics. 2002; 110: 911-19.

[211] Gaethofs M, Verdonck A, Carels C, de Zegher F. Delayed dental age in boys with constitutionally delayed puberty. Eur J Orth.1999; 21: 711-715.

[212] Schmeling A, Schmidt S, Schulz R, Olze A, Reisinger W, Vieth V. Practical imaging techniques for age evaluation. In: Black S, Aggrawal A, Payne-James J, editors. Age

estimation in the living: the practitioners guide. Singapore: Markono Print Media Pte Ltd.; 2010. p.131-133.

[213] Public Health England. Ionising Radiation: Dose Comparisons. [Internet]. 2011 [cited on 2017 Dec 12]. Available from: https://www.gov.uk/government/publications/ionising-radiation-dose-comparisons/ionising-radiation-dose-comparisons

[214] Personal communication with Prof. Graham Roberts, King's College Dental Institute and as stated on the King's College Dental Institute approved information sheet and consent form 2017.

[215] Roberts GJ. Lucas VS. Ethical dental age assessment. Letter to editor. Br Dent J. 2009; 207(6): 251-253.

[216] *London Borough of Croydon v Y* [2016] EWCA Civ 398. [Internet]. [Cited 2017 Jan 6] Available from: [2016] EWCA Civ 398

[217] Husband J. X-rays and x-rated. BDJ in Practice. 2016; 22: 3.

[218] Horner K. Update: new regulations on x-ray use - likely implications of IRR17 and IRMER18. [Internet]. Faculty of General Dental Practice (UK); 2017 Dec 13 [cited 2020 May 12]. Available from: https://www.fgdp.org.uk/news/updated-new-regulations-x-ray-use-likely-implications-irr17-and-irmer18

[219] Franklin D, Flavel A, Noble J, Swift L, Karkhanis S. Forensic age estimation in living individuals: methodological considerations in the context of medico-legal practice. Res Rep Forensic Med Sci. 2015; 5:53-66.

[220] Australian Human Rights Commission (AHRC). An age of uncertainty: inquiry into the treatment of individuals suspected of people smuggling offences who say that they are children. [Internet]. AHRC; Sydney, NSW; 2012 [cited 2017 Dec 1]. Available from: www.humanrights.gov.au/publications/age-uncertainty-inquiry-treatment-individuals-suspected-people-smuggling-offences-who-3

[221] Doyle E, Márquez-Grant N, Field L, Holmes T, Arthurs OJ, van Rijn RR, Hackman L, Kasper K, Lewis J, Loomis P, Elliott D, Kroll J, Viner M, Blau S, Brough A, Martín-de las Heras S, Garamend PM. Guidelines for best practice: Imaging for age estimation in the living. J Forensic Radiol Imaging. 2019; 16: 38-49.

[222] General Dental Council. Focus on Standards. [Internet]. London: General Dental Council. 2020 [cited 2020 May 6]. Available from: https://standards.gdc-uk.org/pages/principle3/principle3.aspx

[223] Heathcote-Curtis R. The myth about consent forms. BDJ in Practice. 2020; 33(4): 23.

[224] de Tobel J, Radesh P, Vandermeulen D, Thevissen PW. An automated technique to stage lower third molar development on panoramic radiographs for age estimation: a pilot study. J Forensic Odontostomatol. 2017; 35(2): 42-54.

[225] Cole TJ. Hot potato topic. Br Dent J. 2008; 205:581-582.

[226] Cunha E. The problem of ageing human remains and living individuals: a review. Forensic Sci Int. 2009; 193(1-3): 1-13.

[227] Thevissen PW, Fieuws S, Willems G. Human dental age estimation using third molar developmental stages: does a Bayesian approach outperform regression models to discriminate between juveniles and adults? Int J Legal Med. 2010; 124: 35-42.

[228] Sironi E, Pinchi V, Pradella F, Focardi M, Bozza S, Taroni F. Bayesian networks of age estimation and classification based on dental evidence: a study on third molar mineralization. J Forensic Leg Med. 2018; 55: 23-32

[229] Konigsberg LW, Frankenburg SR, Liversidge HM. Status of mandibular third molar development as evidence in legal age threshold cases. J Forensic Sci. 2018: 64: 680-697.

[230] European Council on Refugees and Exiles (ECRE). Belgium: age assessment decision overturned as reasoning was deemed insufficient. [Internet]. Brussels, Belgium: European Database of Asylum Law (EDAL); 2019 Dec 9 [cited on 2020 May 15]. Available from:

https://www.asylumlawdatabase.eu/en/content/belgium-age-assessment-decision-overturned-reasoning-was-deemed-insufficient

[231] Council of State, Belgium. *Diallo v the Belgian State* (Case 246.340 of 9 December 2019). [Internet]. Belgium: Council of State; 2019 [Cited on 8 May 2020]. Available from: http://www.raadvst-consetat.be/arr.php?nr=246340&l=fr

[232] *R (on the application of AS (by his litigation friend Francesco Jeff) v Kent County Council (age assessment; dental evidence)* [2017] UKUT 00446 (IAC).

[233] Office of National Statistics. Ethnicity and national identity in England and Wales: 2011. [Internet]. 2012 [cited 2020 Jul 29]. Available from: https://www.ons.gov.uk/peoplepopulationandcommunity/culturalidentity/ethnicity/articles/ethnicityandnationalidentityinenglandandwales/2012-12-11

[234] Connelly R, Gayle V, Lambert PS. Ethnicity and ethnic group measures in social survey research. Methodological Innovations. 2016; 9: 1-10.

[235] Dawkins R, Wong Y. The ancestor's tale: a pilgrimage to the dawn of life. London: Weidenfeld & Nicolson; 2017.

[236] Sykes B. The seven daughters of Eve. Reading, UK: Cox & Wyman Ltd; 2002. p.142.

[237] Sykes B. The seven daughters of Eve. Reading, UK: Cox & Wyman Ltd; 2002. p.338-357.

[238] Sykes B. DNA USA A genetic portrait of America. New York, USA: Liveright Publishing Corporation; 2012.

[239] Pardis C, Sabeti MD. Natural selection: uncovering mechanisms of evolutionary adaptation to infectious disease. Nature Education. 2008; 1(1):13. [Cited 14 May 2020]. Available from: https://www.nature.com/scitable/topicpage/natural-selection-uncovering-mechanisms-of-evolutionary-adaptation-34539/

[240] Mincer HH, Harris EF, Berryman HE. The A.B.F.O. study of third molar development

and its use as an estimator of chronological age. J Forensic Sci. 38(2):379-90. Erratum in J Forensic Sci .1993; 38(6):1524.

[241] Liversidge HM, Marsden PH. Estimating age and the likelihood of having attained 18 years of age using mandibular third molars. Br Dent J. 2010. 209 (8): E13. doi:10.1038/sj.bdj.2010.976.

[242] Thevissen PW, Alqerban A, Asaumi J, Kahveci F, Kaur J, Kim YK, Pittayapat P, Van Vlierberghe M, Zhang Y, Fieuws S, Willems G. Human dental age estimation using third molar developmental stages: accuracy of age predictions not using country specific information. Forensic Sci Int. 2010; 201: 106-111.

[243] Liversidge H, Chaillet N, Mörnstad H, Nyström M, Rowlings K, Taylor J, Willems G. Timing of Demirjian's tooth formation stages. Ann Hum Biol. 2006; 33: 454-470.

[244] Olze A. Taniguchi M, Schmeling A. Zhu B, Yamada Y, Maeda H, Geserick G. Comparative study on the chronology of third molar mineralization in a Japanese and a German population. Leg Med (Tokyo). 2003; 5S: S256-S260.

[245] Kasper K, Austin D, Kvanli A, Rios T, Senn D. Reliability of third molar development for age estimation in a Texas Hispanic population: a comparison study. J Forensic Sci. 2009; 54: 651-657.

[246] Maki K. Morimoto A. Nishioka T. Kimura M. Braham RL. The impact of race on tooth formation. ASDJ Dent Child. 1999; 66(5): 294-295, 353-356.

[247] Olze A, Ishikawa T, Xhu BL, Schulz R, Heinecke A, Maeda H, Schmeling A. Studies of the chronological course of wisdom tooth eruption in a Japanese population. Forensic Sci Int. 2008; 174: 203-206.

[248] Olze A, Peschke C, Schulz R, Schmeling A. Studies of the chronological course of wisdom tooth eruption in a German population. J Forensic Leg Med. 2008; 15(7) 426-442.

[249] Schmeling A, Olze A, Pynn BR, Kraul V, Schilz R, Heinecke A, Pfeiffer H. Dental age estimation based on third molar eruption in First Nations People of Canada. J Forensic Odontostomatol. 2010; 28(1): 32-38.

[250] Martin-de-las-Heras P, Garci-Fortea A, Ortega A, Zodocovich S, Valenzuela A, Third molar development according to chronological age in populations from Spanish and Magrebian origin. Forensic Sci Int. 2008; 174: 47-53.

[251] Chagula WK. The Age at Eruption of Third Permanent Molars in Male East Africans. Am J Phys Anthropol. 1960; 18:77-82.

[252] Suk V. Eruption and decay of permanent teeth in Whites and Negroes with comparative remarks on other races. Am J Phys Anthropol. 1919; 2:351-388 cited in Chagula WK. The age at eruption of third permanent molars in male East Africans. Am J Phys Anthropol. 1960; 18:77-82.

[253] Garn SM, Wertheimer F, Sandusky ST, McCann MB. Advanced tooth emergence in negro individuals. J Dent Res. 1972; 51: 1506.

[254] J Hassanali. The third permanent molar eruption in Kenyan Africans and Asians. Ann Hum Biol. 1985; 12:517-523.

[255] Odusanya SA, Abayomi IO. Third molar eruption among rural Nigerians. Oral Surg Oral Med Oral Pathol. 1991; 71:15-4.

[256] Otuyemi OD, Ugboko VI, Ndukwe KC, Adekoya-Sofowora CA. Eruption times of third molars in young rural Nigerians. Int Dent J. 1997; 47: 266-270.

[257] Andrews SE. Third molar observations in a sample of British male young offenders. Sci Justice. 2015; 55: 274-8.

[258] Blankenship JA, Mincer HH, Anderson KM, Woods MA, Burton EL. Third molar development in the estimation of chronologic age in American Blacks as compared with Whites. J Forensic Sci. 2007; 52: 428-83.

[259] Liversidge HM. Timing of human mandibular tooth formation. Ann Hum Biol. 2008; 35: 294-321.

[260] Tompkins RL. Human population variability in relative dental development. Am J Phys Anthropol. 1996; 99: 79-102.

[261] Moze K, Roberts G. Dental age assessment (DAA) of Afro-Trinidadian children and adolescents. Development of reference dataset (RDS) and comparison with Caucasians resident in London, UK. J Forensic Leg Med. 2012; 19: 272-279.

[262] Olze A. Schmeling A. Taniguchi M. Hitoshi M. van Nierkirk P, Geserick G. Forensic age estimation in living subjects: the ethnic factor in wisdom tooth mineralisation. Int J Legal Med. 2004; 118: 170-3.

[263] Jayakumar J, Wong HM, King NM, Roberts GJ. The French-Canadian data set of Demirjian for dental age estimation: A systematic review and meta-analysis. J Forensic Leg Med. 2013; 20: 373-381.

[264] Ambarkova V, Galic I, Vodanovic M, Biocina-Lukenda D, Brkic H. Dental age estimation using Demirjian and Willems methods: cross-sectional study on children from the Former Yugoslav Republic of Macedonia. Forensic Sci Int. 2014; 234: 187.e1- 187.e7

[265] Acharya AB. Age estimation in Indians using Demirjian's 8-teeth method. J Forensic Sci. 2011; 56: 124-127.

[266] Dhamo B, Kragt L, Grgic O, Vucic S, Medina-Gomez C, Rivadeneira F, Jaddoe VWV, Wolvius EB, Ongkosuwito EM. Ancestry and dental development: a geographic and genetic perspective. Am J Phys Anthropol. 2017; 1-10.

[267] Aynsley-Green A. Unethical age assessment. Br Dent J. 2009; 206: 337

[268] Jayaraman J, Roberts GJ. Comparison of dental maturation in Hong Kong Chinese and United Kingdom Caucasian populations. Forensic Sci Int. 2018; 292: 61-70.

[269] Elshehawi W, Alsaffar H, Roberts G, Lucas V, McDonald F, Camilleri S. Dental age assessment of Maltese children and adolescents: development of a reference dataset and comparison with a United Kingdom Caucasian reference dataset. J Forensic Leg Med. 2016; 39: 27-33.

[270] Roberts G, McDonald F, Lucas VS. Letter to the Editor: age assessment by Demirjian's development stages of the third molar: a systematic review. Eur Radiol. [Internet] 2019 Apr 4 [cited 2020 Sept 9] Available from: https://www.european-radiology.org/opinions/letter-editor-age-assessment-demirjians-development-stages-third-molar-systematic-review/

[271] Southwark Giving. Report: a tale of two Southwarks: a needs analysis of the London Borough of Southwark. [Internet]. London; 2016 [cited 2020 Jan 4]. Available from: http://southwarkgiving.org/research-report-sections. Accessed April 25th 2019]

[272] Office for National Statistics. 2011 Census: key statistics and quick statistics for local authorities in the United Kingdom. [Internet]. UK; 2013 [cited 2020 May 18]. Available from:
2011 Census: Ethnic group, local authorities in the United Kingdom".

[273] Pears, Elizabeth. 2011 Census: British Africans now dominant black group. [Internet]. The Voice. 2012 Dec 12 [cited 2020 May 18]. Available from: *"2011 Census: British Africans now dominant black group"*.

[274] The Migration Observatory at the University of Oxford. Migrants in the UK: an overview. [Internet]. Oxford: Centre on Migration, Policy and Society (COMPAS) [updated 2019 Oct 4; cited 2020 May 18]. Available online at: https://migrationobservatory.ox.ac.uk/resources/briefings/migrants-in-the-uk-an-overview/

[275] Community Action Southwark. Demographic data for Southwark from the 2011 census. [Internet]. London: Community Action Southwark, 1 Addington Square, SE5 0HF; [cited 2020 May 18]. Available from: https://communitysouthwark.org/sites/default/files/images/Southwark%20demography%20from%202011%20Census.pdf

[276] The Migration Observatory at the University of Oxford. Migration to the UK: asylum and resettled refugees. [Internet]. Oxford: Centre on Migration, Policy and Society (COMPAS). [Updated 2019 Nov 8; cited 2020 May 18] Available from: https://migrationobservatory.ox.ac.uk/resources/briefings/migration-to-the-uk-asylum/

[277] Afkhami R. Ethnicity: introductory user guide. 2012 and January 2012 update. Colchester: Economic and Social Data Service cited by The Migration Observatory at the University of Oxford. Migration to the UK: asylum and resettled refugees. [Internet]. Oxford: Centre on Migration, Policy and Society (COMPAS). [Updated 2019 Nov 8; cited 2020 May 18] Available from: https://migrationobservatory.ox.ac.uk/resources/briefings/migration-to-the-uk-asylum/ .

[278] Mathur R, Grundy E, Smeeth L. National Centre for Research Methods Working Paper 01/13: Availability and use of UK based ethnicity data for health research. [Internet]. UK; March 2013 [cited 2017 Nov 12]. Available from: http://eprints.ncrm.ac.uk/3040/1/Mathur-_Availability_and_use_of_UK_based_ethnicity_data_for_health_res_1.pdf

[279] Planmeca OY. Planmeca Romexis® dental imaging software [Internet]. Finland: Planmeca OY; 2020 [cited 2020 May 23]. Available from: https://www.planmeca.com/software/key-benefits/

[280] Based on illustrations available from Planmeca OY. Planmeca Romexis® 2D dental imaging [Internet]. Finland: Planmeca OY; 2020 [cited 2020 April 29]. Available from: https://www.planmeca.com/software/software-modules/planmeca-romexis-2d-imaging/

[281] Personal communication with Professor Graham Roberts, King's College Dental Institute, 2016.

[282] Chudasama PN, Roberts GJ, Lucas VS. Dental age assessment (DAA): a study of a Caucasian population at the 13 year threshold. J Forensic Leg Med. 2012; 19: 22-28.

[283] Microsoft Corporation. Microsoft Access™ version 18.2006.1031.0

[284] Microsoft Corporation. Microsoft Excel™ version 18.2006.1031.0

[285] StataCorp 2013. Statistical Software: Release 13.0. College Station, TX: Stata Corporation.

[286] Personal communication with Professor Graham Roberts, King's College Dental Institute, 2017.

[287] Olze A, van Niekerk P, Ishikawa T, Zhu BL, Schulz R, Maeda H, Schmeling A. Comparative study on the effect of ethnicity on wisdom tooth eruption. Int J Legal Med. 2007; 121: 445-448.

[288] Drawings taken from originals (as shown in Figure 1) in Demirjian A, Goldstein H, Tanner JM. A new system of dental age assessment. Human Biology. 1973; 45: 211-27.

[289] Roberts GJ, McDonald F, Andiappan M, Lucas VS. Dental age estimation (DAE): data management for tooth development stages including the third molar. Appropriate censoring of stage H, the final stage of tooth development. J Forensic Leg Med. 2015; 36: 177-184.

[290] Boonpitaksathit T, Hunt N, Roberts GJ, Petrie A, Lucas VS. Dental age assessment of adolescents and emerging adults in United Kingdom Caucasians using censored data for stage H of third molar roots. Eur J Orthod. 2011; 33: 503-508.

[291] Elshehawi W, Alsaffar H, Roberts G, Lucas V, McDonald F, Camilleri S. Dental age assessment of Maltese children and adolescents: development of a reference dataset and comparison with a United Kingdom Caucasian reference dataset. J Forensic Leg Med. 2016; 39: 27-33.

[292] Roberts G, McDonald F, Lucas VS. Letter to the Editor: age assessment by Demirjian's development stages of the third molar: a systematic review. Eur Radiol. [Internet] 2019 Apr 4 [cited 2020 Sept 9] Available from: https://www.european-radiology.org/opinions/letter-editor-age-assessment-demirjians-development-stages-third-molar-systematic-review/

[293] Liversidge H. Dental age revisited. In: Irish J, Nelson G, editors. Technique and Application in Dental Anthropology: Cambridge studies in biological and evolutionary anthropology. Cambridge: Cambridge University Press; 2008. p 234-252. doi:10.1017/CBO9780511542442.010

[294] Personal communication with Professor Dirk Bister, Department of Orthodontics, King's College Dental Institute, July 2019.

[295] Personal communication with forensic anthropologists at British Association for Human Identification (BAHID) Autumn Conference, 2019 and personal communication with Gillian Fowler, Lead Consultant in Forensic Anthropology and Archaeology, Alecto Forensic Services, 2020 Jul 17.