Dental age assessment (DAA): Reference data for British caucasians at the 16 year threshold

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ABSTRACT

The purpose of this study was to determine reference data for dental age assessment (DAA) for the 16 year threshold in British caucasians.

Patients, materials and methods: One thousand seven hundred and twenty-two Dental Panoramic Radiographs of individuals aged between 4 and 24 years were re-used to establish reference intervals using the tooth development stages (TDSs) previously described [A. Demirjian, H. Goldstein, J.M. Tanner, A new system of dental age, assessment, Human Biology 45 (1973) 221–227]. All teeth present in the left maxilla and mandible, and the third permanent molars were assessed. In addition, to test the accuracy of DAA, the radiographs of a study sample of 50 children of known chronological age (CA) were assessed in the same manner as the reference population. These were aged between 15 and 17 years and separate from the database. For each subject in the study sample a new method of mathematical manipulation based on meta-analysis was applied to all teeth that were still developing [G.J. Roberts, S. Parekh, A. Petrie, V.S. Lucas, Dental age assessment (DAA): a simple method for children and emerging adults, British Dental Journal 204(4) (2008) 192–193]. The estimated calculated average of all the teeth present on the radiograph of each individual generated by the meta-analysis was assigned to each individual as the dental age. For each test subject this was then compared to the gold standard of chronological age.

Results: The average difference between dental age and chronological age for individuals in the test sample was 0.27 years (3.24 months) in females and 0.23 years (2.76 months) in males.

Conclusion: Dental age assessment obtained by calculation of tooth development stages using meta-analysis provides estimates of age around the 16 year threshold.

1. Introduction

Cross-border immigration has resulted in increasing numbers of individuals of unknown birth date arriving in the United Kingdom. Estimating chronological age is important for civil, criminal, forensic and anthropologic purposes. There are several methods of estimating age including questionnaires complied by social services, physical examination, wrist radiographs and dental assessment using a Dental Panoramic Tomograph (DPT) [3].

Radiographs provide a permanent record of a moment of the progressive sequence of dental development. A defined scale of maturity, between early development and maturity may be mathematically manipulated to relate to chronological age (CA) [4]. Several workers have assessed methods of DAA [5,6] and the most common method of estimating dental age is reported to be that based on French Canadian children [1,4] of reproducibility between examiners has been demonstrated using this method [7–9].

Standardizing the methodology of DAA is needed to generate reliable reference studies [5,10,11]. For example, it is important not to use data from both sides of the jaw as this would prejudice the independence of the sample data. Because tooth development is bilaterally symmetrical it is appropriate to use teeth from only one side [4,14]. It is important to have a sufficiently large sample to generate ethnic and gender-specific reference standards [3,10]. A recent novel advance in the handling of summary data of tooth development stages (TDSs) involves the use of the mathematical techniques of meta-analysis [2].

In late adolescents and emerging adults the third permanent molar may be the only remaining tooth to have not yet reached maturity [12]. Estimating age using other biological indicators may be inappropriate in this population [13,14]. The maturity of the third permanent molar could be the only suitable means for estimating age in subjects of unknown birth date for emerging adults [13]. Because of the relatively frequent absence of one or

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more of the 3rd permanent molars it is appropriate to provide and use summary data for each of the four 3rd molars [13].

It has been reported that estimated age was more accurate when both a maxillary and mandibular 3rd molar were assessed together [15]. It could be suggested that greater precision may be achieved by examining all 3rd permanent molars [13].

Many studies have demonstrated that dental maturity is more advanced in girls compared with boys [4,10,16,17]. Conversely when using the 3rd permanent molar tooth for DAA, dental maturity appeared to be more advanced in boys [12,14,15,18]. For this reason the data has been partitioned by gender.

The 16 year threshold was investigated because individuals under this age in the UK are deemed incompetent to consent to sexual activity. The UK police have made a number of requests for age assessment of young people where illegal sexual activity has been suspected. In addition, young people under the age of 16 years are unable to give consent for marriage.

The purpose of this work was to provide reference data around the 16 year threshold for female and male caucasian subjects in the United Kingdom. Further, to assess the precision of a simple technique of dental age assessment [2] for this age group.

2. Patients, materials and methods

Ethical approval was granted by both King's College Hospital NHS Trust Research and Development Committee (Reference: 06DS03) and The Eastman Dental Hospital (Reference: 03/E02). The study was registered with The Data Protection Officer of King's College Hospital NHS Trust to comply with Data Protection Legislation.

2.1. Reference sample

This comprised re-used DPTs of caucasian adolescents within the 4–24 year age range, retrieved from King's College Dental Hospital and Eastman Dental Hospital archives. Radiographs of individuals with conditions that could influence the rate of dental development, for example a growth hormone or genetic disorder, or with poor quality images were excluded. If a tooth was absent, affected by pathology or the radiographic image was distorted, the contra lateral tooth was substituted where possible. The date of birth of each subject was hidden from the investigator. To maximise the number of 15–17-year-old subjects in the reference sample, additional radiographs in this age range were specifically sought from the archives.

2.2. Study sample

This comprised a group of 50 re-used DPTs that were completely separate from the reference sample. These were from caucasian individuals of known chronological age, between 15 and 17 years and were used to test the accuracy of DAA around the 16 year threshold.

2.3. Image capture

Each radiograph was copied using a Pentax Digital Camera. The computer images were stored and examined (using Paint Shop Pro version 9.0, Jasc Software Inc., U.S.).

2.4. Dental age assessment of reference and study sample

All developing teeth on the left side and all four 3rd permanent molars, were assessed using the eight stages of tooth development system (Fig. 1).
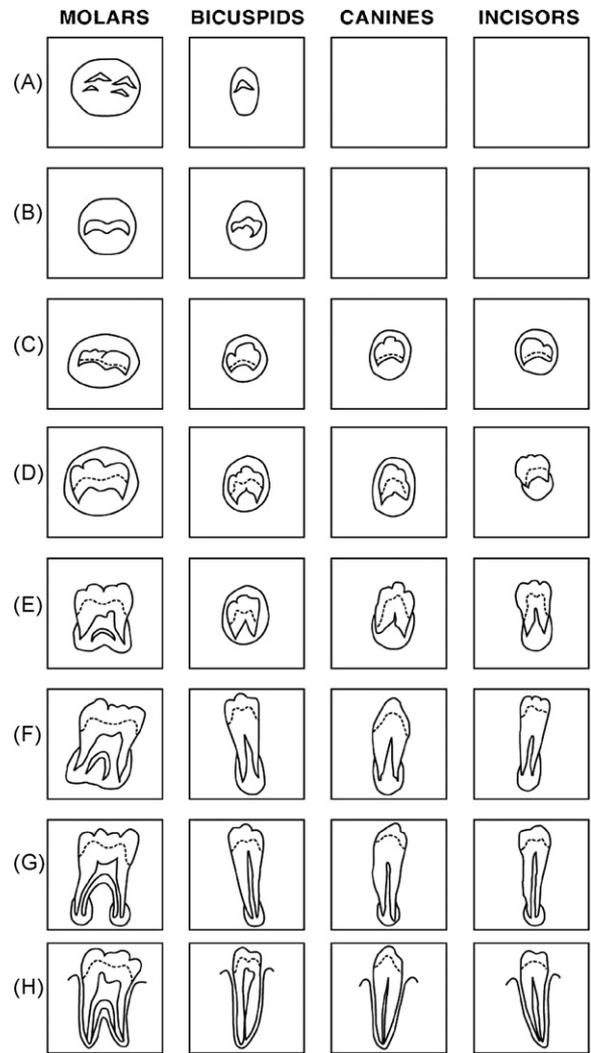

Fig. 1. Aide de Memoire for Dental Development Stages after [4].

The assessment of all TDS for a single case was entered into a proforma. These data were entered into a database (Access 2003 Microsoft®) for manipulation of numerical data (Fig. 2).

2.5. Inter-rater agreement

This was assessed for both investigators (intra-rater agreement) comparing assessments 2 weeks apart and between investigators

Chronological Age = 16.06 year   Dental Age = 15.90

Fig. 2. Dental Panoramic Tomograph of Child ID No. DH175002, initials RC chronological age = 16.06 year, dental age = 15.90.

(inter-rater agreement). This was determined by assessment of 321 TDSs (10 radiographs) of subjects of known age.

3. Data management

3.1. Reference sample

The full database comprised 1722 radiographs from caucasian subjects aged between 4 and 24 years. This ensured that all tooth development stages present in the study sample could be 'aged' using the reference data. For example, a subject of just over 15 years old might have present on the radiograph a tooth development stage which was estimated at 13 years.

A set of reference data was established by creating database queries to provide the age range and summary data for each TDS for each developing tooth in caucasians. The preliminary assessment of the data comprised a worksheet for each TDS. This had columns for all the data for each of the TDSs and summary data. For a column of data related to a specific TDS, the following data was derived: number of subjects (n), the mean age (x), the standard deviation (S.D) and by calculation the standard error (S.E). These data for all TDSs, produced a symmetrical frequency distribution for age of attainment of each TDS. These data is normally distributed and provided the information from which the age of individual subjects could be estimated.

3.2. Study sample

The main part of the project was to assess the accuracy of the method using the reference data to determine the age of subjects of approximately 16 years. A separate continuous group of 50 children of known chronological age were used to test the accuracy of the new method. Radiographs of the 50 study subjects were examined and the TDSs for all developing teeth noted with the investigator unaware of the date of birth. Teeth at stage H [1,4] which denotes apex closed were excluded. To estimate age using the mathematical techniques of meta-analysis the following procedures were carried out.

Step 1. TDSs were identified and entered into a table unique to each subject (Table 1). Where the image is of poor quality or root growth is complete, these teeth are treated as missing

Table 1
Summary data (mean and standard error) from subject ID No. DH175002, initials RC in Fig. 2 extracted from excel tables and entered into the data sheet of stata.

Tooth	Stage	X (mean age, years)	S.E. (standard error, years)
Maxillary [L]			
UL1	Ac	-	-
UL2	Ac	-	-
UL3	Ac	-	-
UL4	Ac	-	-
UL5	Ac	-	-
UL6	Ac	-	-
UL7	Ac	-	-
UL8	UL8F	16.22	0.10
UR8	UR8F	16.19	0.08
Mandibular [L]			
LL1	Ac	-	-
LL2	Ac	-	-
LL3	Ac	-	-
LL4	Ac	-	-
LL5	Ac	-	-
LL6	Ac	-	-
LL7	Ac	-	-
LL8	LL8E	15.52	0.11
LR8	LR8E	15.65	0.12

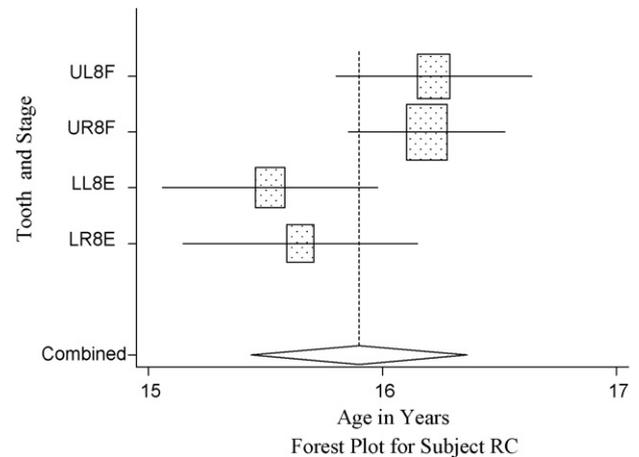Ac indicates stage H, apex closed so data are unusable.

Fig. 3. Results of Meta-analysis of Child ID No. DH175002, initials RC, showing the estimated mean age (the box) and 99% confidence interval of each developing tooth stage. The combined estimated mean dental age for this subject (RC) is indicated by the dotted line and the 99% confidence interval by the horizontal limits of the diamond.

data—shown as a hyphen in the table. If a tooth is missing, but present on the contra lateral side, substitution of this tooth is permitted (e.g. LR7Fm can be substituted for LL7Fm and the summary data for the LL7 is used).

Step 2. The table was then copied and pasted into the spreadsheet of the statistical package. This then produces a mean dental age and 99% confidence intervals with a forest plot (Fig. 3) based on the summary data for the teeth present in each subject in the study group. This may be as little as 2, or as many as 16 teeth [2].

Step 3. For each subject in the study group the only information used from the meta-analysis is the estimated mean age of the population from which the sample is drawn. This estimated mean age is assigned to the subject of unknown date of birth as the dental age. The chronological age, and the dental age derived as above, were assessed using the method comparison technique of Bland and Altman 1986 [19] (Figs. 4 and 5).

In the context of DAA, meta-analysis provides an estimate of the dental age in a subject by calculating a weighted mean of the mean age of the TDSs in that subject, with each weight being proportional to the standard error of the mean age for that TDS [2]. A random effects model has been used for the calculation: it assumes that, in addition to the random variation associated with
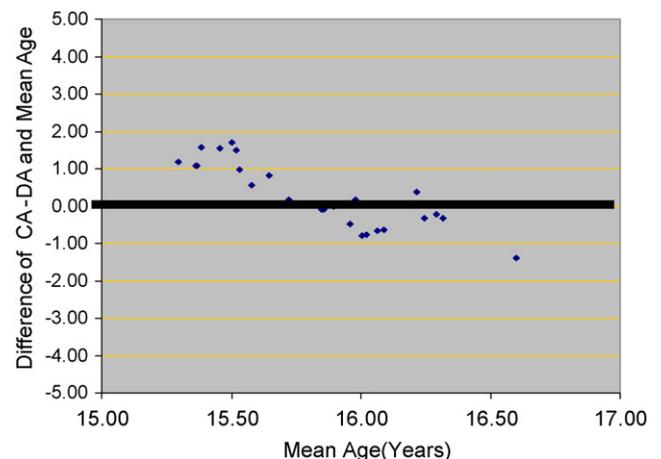

Fig. 4. Measure of agreement between CA and DA in female subjects using meta-analysis excluding subject 45.
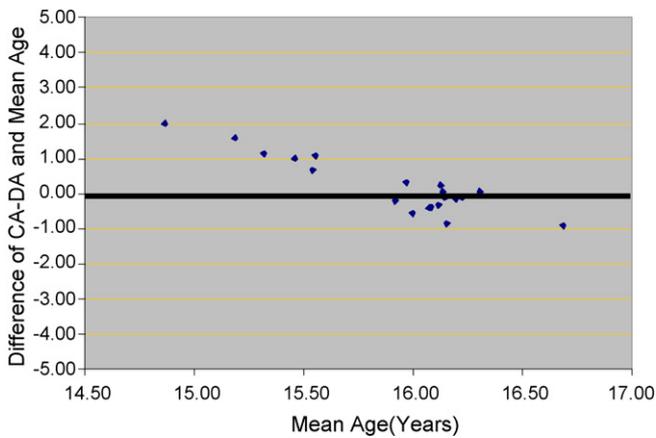
Fig. 5. Measure of agreement between CA and DA in male subjects using meta-analysis excluding subject 16 and 50.

each TDS estimate, there is heterogenicity among the TDS results and it incorporates this source of variation into the calculation [2].

3.3. Testing accuracy of the estimated dental age

Furthermore, a method comparison technique was used to measure the degree of difference between the chronological age and estimated dental age for each study subject [19].

4. Results

4.1. Inter-rater agreement

The intra- and inter-rater agreement Kappa score for the tooth development stages were 0.82 and 0.90, respectively. This demonstrated almost perfect agreement for this method of assessment [20].

4.2. Subject recruitment

4.2.1. Reference set
The reference sample comprised of 1722 caucasian subjects. This consisted of 992 females and 730 males.

4.2.2. Study sample
This consisted of 28 females and 22 males. For the 28 females the mean chronological age was 15.96 years, S.D. 0.21, with 99% confidence interval from 15.84 years to 16.07 years. For the 22 male subjects the mean chronological age was 16.01 years, S.D. 0.17, with 99% confidence interval from 15.91 years to 16.11 years (Table 2).

4.3. Dental age assessment: study sample

Two male subjects (No: 16 and No: 50) and one female subject (No: 45) had insufficient developing teeth to use this method to estimate the dental age so were no longer considered. The mean difference between the chronological age and estimated dental age in female and male subjects using meta-analysis was 0.27 years and 0.23 years, respectively. This method of dental age assessment

Table 3
CA, estimated DA and CA − DA for 28 female subjects and 22 male subjects in the study sample.

Female subjects			Male subjects		
CA	DA	CA − DA	CA	DA	CA − DA
15.90	14.83	1.07	15.87	13.86	2.01
15.85	15.30	0.55	16.25	16	0.25
15.88	14.71	1.17	16.19	16.26	−0.07
15.81	15.90	−0.09	15.90	16.26	−0.36
16.15	16.48	−0.33	16.24	17.13	−0.89
16.06	15.90	0.16	15.74	16.56	−0.82
16.06	15.23	0.83	15.88	16.26	−0.38
16.40	16.03	0.37	16.01	14.02	1.99
15.64	16.40	−0.76	16.10	15	1.10
15.89	15.90	−0.01	15.90	14.73	1.17
15.91	17.29	−1.38	15.73	16.26	−0.53
16.01	15.05	0.96	15.97	16.26	−0.29
15.80	15.90	−0.10	15.88	15.19	0.69
15.91	14.83	1.08	16.35	16.26	0.09
15.73	16.40	−0.67	16.13	16.26	−0.13
16.17	14.60	1.57	15.83	16.00	−0.17
15.86	15.30	0.56	16.10	16.18	−0.08
16.22	14.69	1.53	16.17	16.09	0.08
15.61	16.40	−0.79	15.97	14.95	1.02
16.09	16.40	−0.31	15.88	14.37	1.51
16.35	14.65	1.70	16.15	15.79	0.36
15.81	15.90	−0.09	15.99	14.38	1.61
16.19	16.40	−0.21			
15.72	16.20	−0.48			
15.89	14.00	1.89			
16.27	14.77	1.50			
15.80	15.64	0.16			
15.78	16.40	−0.62			

appears to underestimate chronological age by approximately 3 months. The underestimate was greater in females (0.27 years) than males (0.23 years) (Table 4).

The method comparison technique for female and male study subjects shown in Figs. 4 and 5, respectively shows the measure of agreement between chronological age and dental age [19].

5. Discussion

The use of tooth development stages and the associated summary data has been used for many years to carry out approximate estimates of age [21,22]. None of these studies gave a detailed description of how age was estimated. The major advance was in 1973 when the integrated method based on eight stages of tooth development using only the lower left permanent teeth, excluding the 3rd molar was described for French Canadian children [1,23]. Disadvantages of this technique are that it appears to give inaccurate estimates for other racial and ethnic groups [7,2,25,26] and excluding the use of 3rd molars renders it unusable past the age of 15.75 years.

The current study uses the first part of the Demirjian technique, the tooth development stages, and applies them to the only teeth continuing to develop after 15.92 years of age which are the 3rd permanent molars. The summary data are used to carry out age estimates by investigating the average age of attainment for each TDS present and weighting those values by the distribution and number of each TDS in the reference data. This approach provides a reliable estimate of age which on average, is only a few months

Table 2
The summary data for the chronological age of subjects in the study sample.

Number of subjects	Mean age (years)	Lower 99% confidence limit (years)	Upper 99% confidence limit (years)	Standard deviation
Female, n = 28	15.96	15.84	16.07	0.21
Male, n = 22	16.01	15.91	16.11	0.17

Table 4
Mean difference between estimated DA and CA using meta-analysis: study sample.

Groups	Female (excluding subject 45)	Male (excluding subjects 16 and 42)
Number of subjects	27	20
Mean CA − DA (years)	0.27	0.23

CA: chronological age.
DA: dental age.

different from the gold standard of chronological age (see Tables 3 and 4). Although other investigators have highlighted male and female differences, we have not made gender comparisons. This is because the only purpose of this work was to identify differences between dental age and chronological age. Separation of the data into males and females enabled proper account of the confounding factor of gender [14,15].

Two important features of this study indicate the robust nature of the way that the numerical data is handled. The first is the meticulous training and assessment of the inter-rater agreement both within and between raters. This has been shown to be a common achievement using the eight stages system of TDS and lends strong support to the general applicability of this eight stages system of TDSs [7–9].

The second important feature of this is that the method of DAA has been rigorously tested by estimating the age of a study sample completely separate from the reference sample. These were assessed without knowledge of the date of birth. Once the assessment had been made the date of birth was revealed enabling the use of a method comparison technique [19]. This challenging test of the methodology has provided results that engender confidence when assessing the age of adolescents and emerging adults at approximately the 16 year threshold. A prevailing difficulty is the lack of a method of calculating the probability of a specific subject of unknown date of birth aged 16 years or younger. This is a topic that is currently under investigation. At the moment, there is no recognized statistical technique of averaging the multiple probabilities from all the developing teeth present in an individual subject of unknown date of birth. Further work is required on the question "is this subject of unknown date of birth under or over 16 years of age?". This needs a substantial and carefully selected study sample and is the focus of current work.

These data are offered to support assessment of age in children and emerging adults; the results of which can be assessed with a degree of statistical confidence. An advantage of the use of meta-analysis is that limited numbers of teeth may be used reliably to estimate age.

6. Conclusion

1 The reference intervals for dental age assessment at the 16 year threshold using the eight stages of tooth development have been determined for British caucasians [4].
2 The tooth development stages first described by Demirjian [1] have been extended to all four 3rd permanent molars and all teeth in both the left maxilla and mandible.
3 The accuracy of this method of dental age assessment was tested on a continuous sample of British caucasian adolescents and young adults of known chronological age using a new method of mathematical manipulation based on meta-analysis [2]. This method was shown to predict the dental age to within 0.3 years of an individual's chronological age.

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