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ORIGINAL ARTICLE

Dental age assessment (DAA): reference data for British children at the 10-year-old threshold

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Abstract The purpose of this work was to develop a reference dataset for dental age assessment at the 10-year-old threshold. Dental panoramic radiographs of children aged between 9 and 11 years were reused to determine the age of attainment of tooth development stages relevant to the 10-year threshold. These data were used to test the accuracy of the dental age assessment (DAA) on a separate study sample of known chronological age. The study sample comprised 100 radiographs (50 female, 50 male) of known chronological age that did not form part of the reference dataset. For each subject in the study sample, the mathematical procedure used in meta-analysis was applied to all teeth that were still developing. The weighted average of all the developing teeth in a given child was assigned as the dental age for that individual. This was compared to the gold standard of chronological age. Three thousand six hundred sixty-two radiographs comprised the reference sample. The mean difference between the chronological age and dental age estimated for the sample of female subjects was 0.12 years (1.44 months) and for the males was 0.33 years (3.96 months). A method comparison technique was used to evaluate the difference between the chronological age and estimated dental age for each study subject. This showed a good agreement for both females and males. DAA using meta-analysis provides a simple method of estimating the age of subjects of unknown birth date at the 10-year threshold. This is, presently, the most accurate method of age assessment for individuals of unknown date of birth.

Keywords Dental age assessment · Tooth development · Chronological age

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Introduction

The purpose of dental age assessment is to estimate the chronological age of individuals who have unknown dates of birth. This may be because records have never existed or are lost.

Dental age assessment (DAA) may be carried out for criminal purposes. The formal age of criminal responsibility in England and Wales is 10 years old. Children under the age of ten are deemed incapable of committing a criminal offence and are not charged. According to the 2007 police statistics 3,000 crimes were committed in England and Wales by children under the age of ten [1]. Furthermore, during 2004/2005, 287,013 children aged 11–17 years were convicted of criminal offences. These offences accounted for 20% of the 1.4 million committed in that year [2]. Anecdotal evidence suggests that a number of cases do not proceed because of uncertainty about the age of the child involved. This highlights the importance of accurately establishing age, particularly when a child claims a different age from their true age in order to avoid taking responsibility for their own crimes.

In 2006, the applications for asylum in the UK included 4,710 dependents. The majority of these were children, of whom 3,245 were unaccompanied. Of all applications, the age of the asylum seeker was disputed in 2,270 cases. The main age-disputed nationalities were Afghan, Iranian, Eritrean, Chinese, Iraqi and Somali [3].

UNICEF has reported that there are 50 million children who are currently not registered at birth, depriving them of

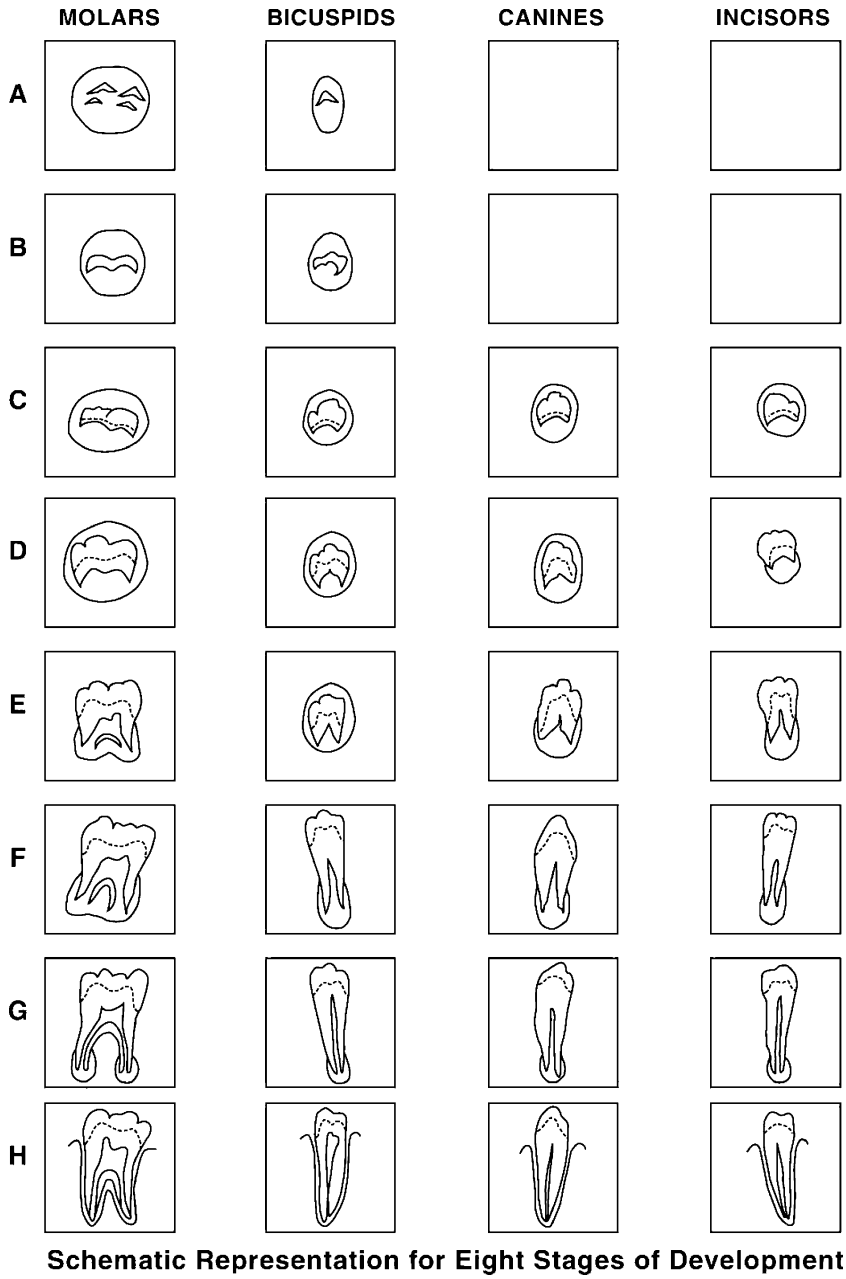

Fig. 1 Schematic drawings of Demirjian eight-stage system used in assignment of tooth development stages (*A–H*) (after Demirjian 1978)

nationality, a legal name and proof of when they were born. Age is an essential information required to assess the need for education and appropriate health care services for young asylum seekers [4].

As the proportion of immigrant children in the UK is likely to increase within the next years, DAA continues to gain importance [5].

In natural disasters, genocide, or murder, estimating the chronological age from human remains may aid the identification of individuals. Anthropological studies using the remains from past civilizations may also benefit from estimating age. For several centuries, the emergence of teeth into the oral cavity was a well-documented method of ageing a child. The exact timing of tooth emergence is difficult to identify, and although it is a convenient and simple method [6], DAA of children by this method is inaccurate. Radiographic techniques to assess tooth development provide a detailed picture allowing developing teeth to be used for estimating age [7]. Detailed work on discrete anatomical descriptions of tooth development led to the eight-stage method [8].

Materials and methods

This study is based on a reference dataset from a convenient sample of children, adolescents and young

Fig. 2 Dental panoramic radiograph of worked example

adults. This involved every radiograph of good diagnostic quality that was available in the archives at the specified age range.

Ethical approval

Ethical approval (REC 06/Q0703/54) was granted by King's College Hospital NHS Trust Research and Development Committee. The study was registered with The Data Protection Officer of King's College Hospital NHS Trust to comply with Data Protection Legislation.

Reference dataset

This comprised reused dental panoramic tomographs (DPTs) of children around the 10-year threshold retrieved from King's College Dental Hospital archives. Radiographs of children with conditions that could influence the rate of dental development, or those with poor quality images, were excluded. The date of birth of each subject was blinded to the investigators when assessing tooth development stages (TDSs). The chronological age of the subjects was calculated within the database using the date of birth and the date of the DPT. Gender and ethnicity were also recorded.

Study sample

An independent sample of 100 DPTs, 50 males and 50 females, of known chronological age was used to test the accuracy of dental age assessment. These were between 9 and 11 years of age.

Image capture

Each radiograph was copied using a Canon digital camera (400D SLR). The digitalized images were stored and examined on a password-protected computer.

Tooth development stages

TDSs were assessed using the method defined by Demirjian [8] (Fig. 1).

TDSs were assessed and recorded for all the permanent teeth on the left side of both the maxilla and mandible in addition to the third permanent molar in each quadrant.

Repeatability

Twelve radiographs for subjects of known age were assessed by the main examiner (MY) on two occasions 2 weeks apart to test intra-rater agreement. Inter-rater agreement using the same radiographs was assessed by the second examiner (GR). The index of agreement was calculated using Cohen's kappa. The categories published by Landis and Koch [9] were used to indicate the degree of agreement.

Summary data for use with DAA

Within the Microsoft Access Database in which all data were entered, it is possible to raise a query to calculate the age of attainment of each TDS present in an individual subject. From these summary data, the mean age of attainment and standard error of each TDS was retrieved.

Meta-analysis for DAA

In the context of DAA, the mathematical technique of meta-analysis is used to provide an estimate of the dental age in a subject by calculating the weighted mean of TDSs in that individual, with each weight being proportional to the variation within the sample (standard deviation) and the number of each TDS [10]. A random effects model is used for the calculation which incorporates the variation between the TDSs into the weight for each TDS. STATA was then

Table 1 Determined tooth development stages (example)

Stages identified on the DPT shown using the Demirjian eight-stage system	UL1	UL2	UL3G	UL4F	UL5F	UL6H	UL7E	–
	LL1	LL2	LL3G	LL4F	LL5F	LL6G	LL7F	–

Table 2 Summary data (example)

Tooth	Stage	*x*	SE
UL1			
UL2			
UL3	UL3G	11.56	0.24
UL4	UL4F	10.03	0.32
UL5	UL5F	10.7	0.32
UL6	UL6H		
UL7	UL7E	9.27	0.31
UL8			
LL1			
LL2			
LL3	LL3G	11.13	0.27
LL4	LL4F	10.27	0.51
LL5	LL5F	10.44	0.14
LL6	LL6G	8	0.24
LL7	LL7F	10.42	0.14
LL8			SE

used to evaluate the accuracy of the estimated dental age by comparing this for each subject with the gold standard of chronological age using a Bland and Altman [11] plot. This type of analysis is known as a method comparison study, which in this case measures the difference between the two methods of determining the age of each subject, that is, the chronological age and estimated dental age.

As a worked example to illustrate the method, the DPT is assessed (Fig. 2).

The tooth development stages determined by the observer are shown in Table 1. In this example, the subject was female.

Once the TDSs have been determined, the numerical data from the reference dataset are entered into a small table (Table 2).

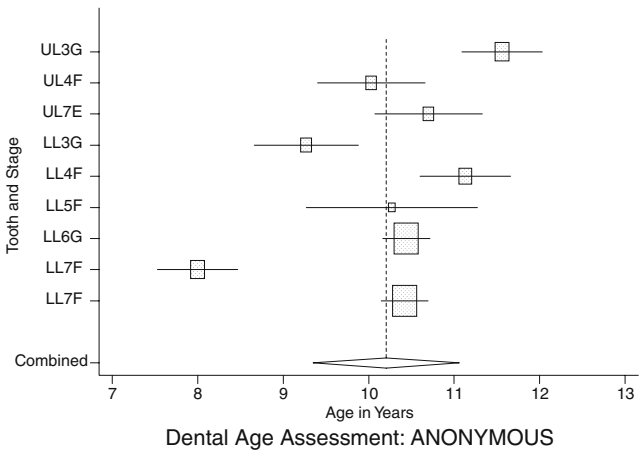

Fig. 3 Forest plot (example)

Table 3 Chronological age vs. dental age assessment: females

Subjects	Chronological age (CA)	Dental age (DAA)	Difference between CA and DA
1	10.19	9.24	0.95
2	10.1	10.80	−0.70
3	10.38	10.38	0.00
4	10.35	10.25	0.10
5	10.6	9.85	0.75
6	10.11	10.68	−0.57
7	11.85	10.86	0.99
8	11.54	12.33	−0.79
9	11.15	9.52	1.63
10	10.68	10.47	0.21
11	10.84	9.89	0.95
12	11.11	10.23	0.88
13	10.41	9.83	0.58
14	9.16	9.00	0.16
15	9.46	9.80	−0.34
16	9.37	9.06	0.31
17	9.29	8.30	0.99
18	9.71	9.43	0.28
19	9.31	8.35	0.96
20	9.2	8.94	0.26
21	9.18	8.24	0.94
22	11.1	11.84	−0.74
23	9.3	9.17	0.13
24	10.57	9.74	0.83
25	10.23	9.30	0.93
26	11.89	13.54	−1.65
27	10.71	10.50	0.21
28	10.28	10.20	0.08
29	10.42	10.10	0.32
30	10.58	11.97	−1.39
31	9.48	9.86	−0.38
32	9.75	10.14	−0.39
33	9.69	10.74	−1.05
34	9.78	9.67	0.11
35	10	10.66	−0.66
36	10.1	10.27	−0.17
37	9.1	8.34	0.76
38	11.6	11.44	0.16
39	9.68	8.11	1.57
40	9.37	10.50	−1.13
41	9.86	10.05	−0.19
42	10.07	9.39	0.68
43	11.45	12.07	−0.62
44	9.51	8.13	1.38
45	9.44	10.34	−0.90
46	9.6	9.03	0.57
47	9.81	9.36	0.45
48	9.11	9.17	−0.05
49	10.46	10.70	−0.24
50	11.09	12.15	−1.06

Table 4 Chronological age vs. dental age assessment: males

Subjects	Chronological age (CA)	Dental age (DAA)	Difference between CA and DA
1	11.19	11.55	−0.36
2	9.60	9.47	0.14
3	11.97	12.64	−0.67
4	9.28	8.3	0.98
5	10.93	12.01	−1.08
6	11.76	11.54	0.22
7	10.46	9.86	0.60
8	11.2	10.4	0.80
9	10.06	9.91	0.15
10	11.01	10.65	0.36
11	9.37	9.64	−0.27
12	9.02	8.82	0.20
13	9.37	8.87	0.50
14	9.14	8.87	0.27
15	10.05	9.19	0.86
16	9.41	8.56	0.85
17	10.8	10.29	0.51
18	9.21	8.76	0.45
19	9.46	9.48	−0.02
20	9.68	8.24	1.44
21	9.37	8.86	0.51
22	9.05	8.88	0.17
23	9.06	9.14	−0.08
24	9.24	8.72	0.52
25	10.22	10.18	0.04
26	10.56	9.59	0.97
27	10.32	9.51	0.81
28	11.79	11.86	−0.07
29	9.23	9.81	−0.58
30	9.64	9.00	0.64
31	9.69	9.42	0.27
32	10.13	8.51	1.62
33	9.23	8.42	0.82
34	10.09	10.45	−0.36
35	10.21	9.70	0.51
36	9.54	8.73	0.81
37	9.28	9.12	0.16
38	10.15	9.70	0.45
39	9.4	8.78	0.63
40	10.24	10.49	−0.25
41	9.82	9.33	0.50
42	9.03	8.56	0.47
43	10.14	9.65	0.49
44	9.38	8.84	0.54
45	9.08	8.76	0.32
46	10.1	9.24	0.86
47	9.19	9.19	0.00
48	9.61	9.30	0.31
49	9.2	9.18	0.02
50	9.22	9.52	−0.30

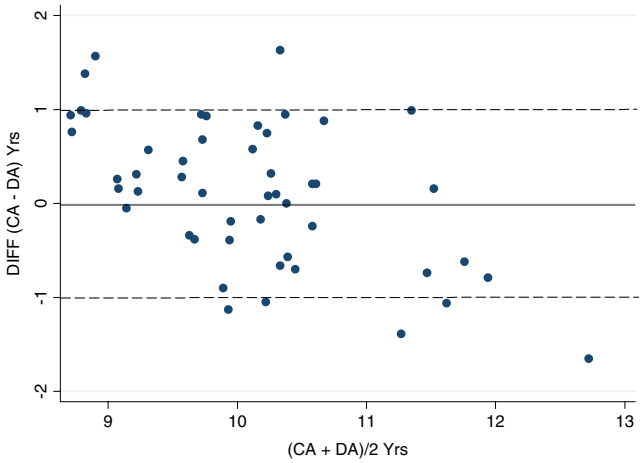

Fig. 4 Measure of agreement between CA and DA in female subjects using meta-analysis

Note that fully formed teeth (stage H) are not used to calculate the weighted average, nor are images of individual teeth which are unusable. The table is then copied to the data editor of STATA and the meta-analysis is performed to calculate the weighted average. The meta-analysis software gives the same results as a weighted average calculation carried out in Excel. The STATA software is much quicker and has the additional benefit of a forest plot (Fig. 3).

Results

Repeatability

The intra-rater agreement kappa for the tooth development stages [8] was 0.7636, indicating a substantial agreement [9], and the inter-rater kappa score was 0.9312, which is an almost perfect agreement.

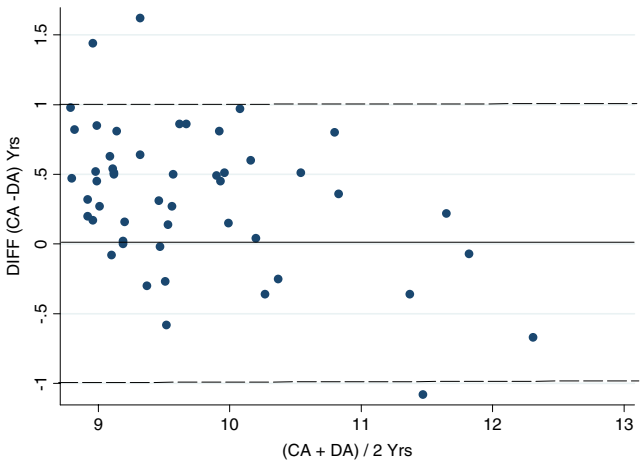

Fig. 5 Measure of agreement between CA and DA in male subjects using meta-analysis

Radiographs of 3,662 subjects comprised the reference sample, of which 545 were added by the main examiner (MY). The number of males and females was approximately equal.

The difference between the chronological age (CA) and dental age (DA) in the study sample was calculated to determine the precision of the method. The mean chronological age, dental age and the difference between the CA and DA are shown in Tables 3 and 4.

The range of ages for the CA is from the calculations based on the date of the radiograph and the date of birth of each child. The study sample was specifically limited to children from the 9- to 11-year age range. The estimated DA using meta-analysis is the case-matched value. As can be seen, the range of values for females for CA is 9.1–11.89 and for males 9.02–11.97.

The mean difference between the chronological age and dental age for females is 0.12 years and for males is 0.33 years.

The agreement between the two sets of data was assessed using Bland and Altman plots (Figs. 4 and 5). These indicated a good level of agreement.

Discussion

The ethical dilemma of assigning a dental age to a child particularly in criminal circumstances should not be overlooked. The assignment of a dental age to a child who may be accused of a crime under investigation will have implications on how the suspected child will be treated by the courts. One of the problems is that the legal process still uses less reliable methods such as a radiograph of the child's wrist.

Although the use of development stages and the associated summary data have been used previously to carry out estimates of age, descriptions of how the age was estimated have not been described in a way that would allow other investigators to repeat the estimates. The methods used in this study have been provided in detail. This is one of the strengths of the study as it is easy for other investigators to use this technique to estimate the age of subjects of unknown date of birth using the data provided here, including using ethnic specific data from other studies (Moze 2009, personal communication, unpublished data). This additional ethnic specific data from Trinidad will be available in the near future. A full reference dataset may be obtained from the authors.

Further strengths include the assessment of repeatability with the intra- and inter-rater agreements which were based on all eight TDSs for each tooth for each radiograph. The very large sample size engenders confidence in the numerical estimates made. Finally, the test of accuracy using a new reference dataset entirely separate from the database has not been described before in the literature at this age threshold.

Although the results depict a high level of accuracy, the main limitation of the study is that it involves assigning a population estimate to an individual. The two main issues which are often questioned are that of ethnic differences and the influences of nutrition. Other investigators have also highlighted male and female differences. This is the very strong justification for separate male and female study samples [12, 13].

Conclusion

The reference dataset for dental age assessment at the 10-year threshold using the eight stages of tooth development was established. The data were based on the utilization of 3,662 radiographs and provided the largest dataset in this age range when compared to current literature.

The accuracy of this method of dental age assessment was rigorously tested with a sample of 100 children, 50 females and 50 males, of known chronological age, separate from the database using weighted averages.

The method was shown, on average, to predict the dental age to within 0.1 years for females and 0.3 years for males of an individual's chronological age.

The independent testing of DAA on separate study samples has shown that this is an accurate method of age assessment at the 10-year threshold.

Ethical standards

We declare that the methods described comply with the current laws of the UK.

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