



Original communication

Dental age estimation: The role of probability estimates at the 10 year threshold

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ABSTRACT

Introduction: The use of probability at the 18 year threshold has simplified the reporting of dental age estimates for emerging adults. The availability of simple to use widely available software has enabled the development of the probability threshold for individual teeth in growing children.

Materials and methods: Tooth development stage data from a previous study at the 10 year threshold were reused to estimate the probability of developing teeth being above or below the 10 year threshold using the NORMDIST Function in Microsoft Excel. The probabilities within an individual subject are averaged to give a single probability that a subject is above or below 10 years old. To test the validity of this approach dental panoramic radiographs of 50 female and 50 male children within 2 years of the chronological age were assessed with the chronological age masked. Once the whole validation set of 100 radiographs had been assessed the masking was removed and the chronological age and dental age compared. The dental age was compared with chronological age to determine whether the dental age correctly or incorrectly identified a validation subject as above or below the 10 year threshold.

Results: The probability estimates correctly identified children as above or below on 94% of occasions. Only 2% of the validation group with a chronological age of less than 10 years were assigned to the over 10 year group.

Conclusions: This study indicates the very high accuracy of assignment at the 10 year threshold. Further work at other legally important age thresholds is needed to explore the value of this approach to the technique of age estimation.

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"To us, probability is the very guide of life" Cicero (106–43 BC) attributed

1. Introduction

The main purpose and justification for age estimation is to ensure that 'separated children in Europe'¹ receive appropriate care and support. The issue of whether or not a child is either above or below a specific age threshold has most effectively been dealt with by estimating the dental age (DA) of the subject.^{2–4} The result of this has been very satisfactory, providing an estimate usually within, or close to, 3 months of the chronological age (CA). An

alternative way to approach this issue is to calculate the probability that a subject of unknown date of birth is either above or below a specific age threshold. This concept was first presented in a publication relating to the third molar.⁵ It was reported that the presence of a lower left third molar, LL8 stage H, indicated the probability of the subject being aged greater than 18 years was 0.9220 [92.2%] for females, and 0.9010 [90.10%] for males. These are compelling results that support the application of the principle of probability for providing age assignments at a specific threshold. This has been shown using multiple developing teeth in children.⁶ Results expressed as probability are easily converted to percentages that are straightforward for non-clinicians to understand. This is particularly important for solicitors, barristers, social workers and the subjects involved.

The use of specific thresholds is important in the UK. Ten years is the age of criminal responsibility,² 13 years is the age below which sexual intercourse with a child is deemed to be statutory rape,³ 16 years is the age below which a child is not legally able to give permission for sexual activity.⁴

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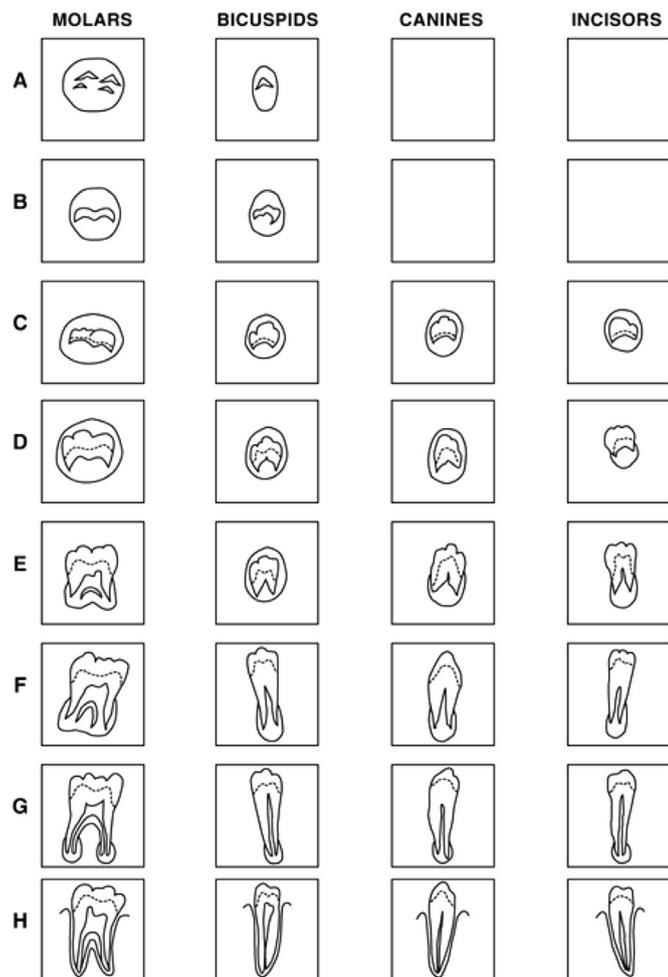
The purpose of this investigation is to explore the potential role of probability estimates in determining whether a child is above or below a specific age. In this study this is the 10 year threshold.

2. Materials and methods

The Reference Data Set (RDS) for this study has been established by the DARLInG research group at King's College London.⁷ (see Appendix A.) Ethical approval was granted by the NRES Committee South Central – Oxford C/Reference Number 12/SC/0029. All the radiographs used were archive material in Departments of Dental Radiology from London. The validation samples comprised 50 females and 50 males, age range 8–12 years. These were separate from the radiographs comprising the RDS. The validation sample radiographs were examined in random order after the chronological age was masked.

The process of estimating the probability that a subject was below the 10 year threshold is as follows.

- i The radiograph of the subject of unknown date of birth is examined. In this study the date of birth is known but masked from the examiner carrying out the TDS assessments and not revealed until the chronological age and dental age are compared. The maturity of the *developing* teeth on the left side and the appropriate corresponding scores are assessed after



Schematic Representation for Eight Stages of Development

Fig. 1. Schematic representation of the Tooth Development Stages after Demirjian.⁸

Table 1
Descriptons of Tooth Development Stages by Demirjian et al. (1973).⁸

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

Demirjian et al. (1973)⁸ (Fig. 1 and Table 1). Each of the 16 Tooth Morphology Types on the left side is assigned a letter from A to H.

The data extracted from the RDS for one subject are shown in the spreadsheet comprising Table 2. This spreadsheet contains in column I the data derived in relation to the Tooth Development Stages (TDSs) in Fig. 2. Column II shows all the TDSs; there is no data for UL1, UL2, LL2, and LL1 because growth is complete and the root apices are closed. Column III, n-tds, shows the number of teeth in the RDS that have attained a given stage. For example, UL3 stage G n-tds is 26 which means that 26 upper left canines have attained stage F and are recorded in the DARLInG database. Column IV, x-tds, is the mean age of attainment of the TDS. For example, for the UL3, the mean age of attainment of stage F in the RDS is 9.23 years. Column V is the standard deviation. Column VI is the standard error which is calculated from Column III (n-tds) and Column V (sd-tds). Column VII is the calculated probability for each of the developing teeth in Column I. the probability is calculated using the NORM.DIST function in Microsoft Excel⁹ (see Fig. 3).

Table 2
Facsimile of Excel Spreadsheet with data to calculate the probability of the age above or below the 10 year threshold. Data from DARLInG RDS.

I Tooth	II Stage	III n-tds	IV x-tds	V sd-tds	VI se-tds	VII p-tds-10
UL1						
UL2						
UL3	F	26	9.23	1.61	0.32	0.68
UL4	F	18	10.51	1.66	0.39	0.38
UL5	G	28	12.60	1.66	0.31	0.06
UL6						
UL7	E	15	9.27	1.19	0.31	0.73
UL8	B	12	11.33	1.99	0.57	0.25
LL8						
LL7	E	26	8.97	2.29	0.45	0.67
LL6						
LL5	F	37	12.10	2.96	0.49	0.24
LL4	F	24	10.50	2.89	0.59	0.43
LL3	G	36	11.13	1.44	0.24	0.22
LL2						
LL1						

$P < 10 \text{ years} = 0.34 [34\%]$ $P > 10 \text{ years} = 0.66 [66\%]$.



Fig. 2. Dental Panoramic Tomograph of male child with CA of 10.46 years old.

Once the full array of data for *developing* teeth has been entered (Table 2) the spreadsheet returns the probability that the subject is under 10 years. The example returns $P = 0.34 [34.00\%]$. The corollary to this is that there is $1 \text{ minus } 0.34 = 0.66 [66\%]$ probability of the subject being *over* 10 years old.

The data for this subject can be visualised using a Forest plot of the TDSs contributing to the overall probability value (Fig. 4).

These procedures were repeated for each of the validation group subjects comprising 50 females and 50 males.

These data are then entered into a table to indicate correct and incorrect assignment (Table 3). This is achieved by first calculating the CA for each validation subject. The related probability then gives 4 possible outcomes described below the subtotals of which are shown Table 4.

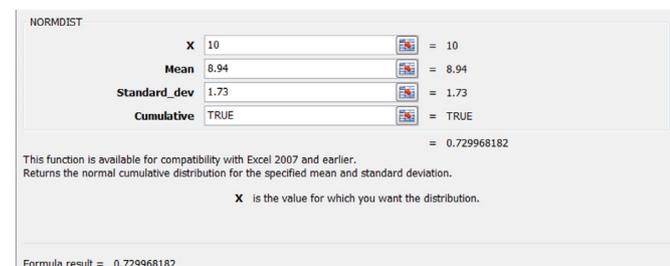


Fig. 3. NORMDIST function in example above from Excel.⁹ $X = 10$ year threshold. $p < 10 = 0.73 [73\%]$; $p > 10 = 0.27 [27\%]$.

**Probability for each
TDS = < 10 years**

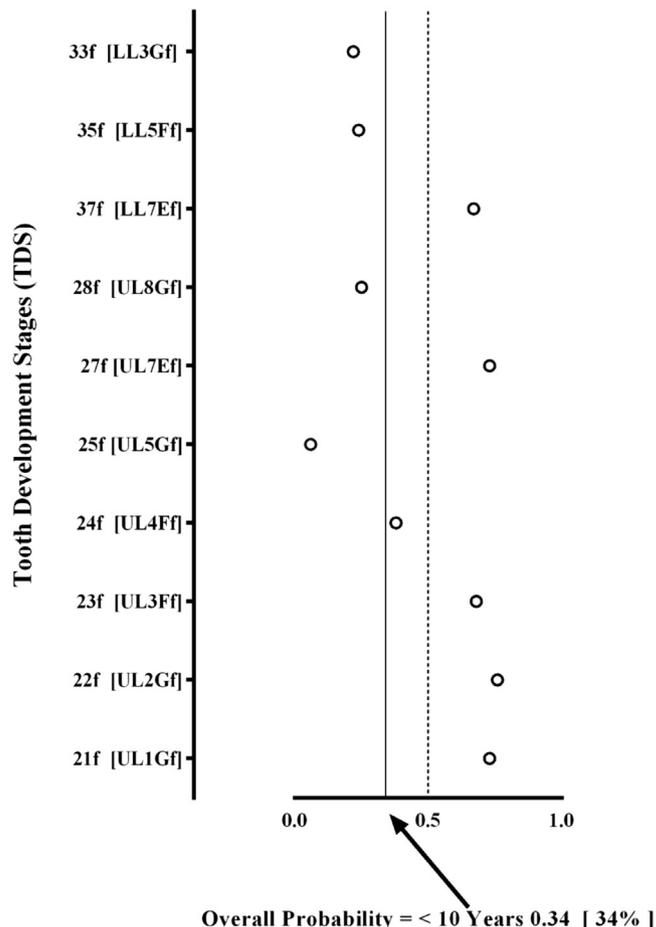


Fig. 4. Forest plot of Tooth Development Stages probability and overall probability.

The findings are displayed for both females and males for the weighted probabilities in Table 3.

3. Discussion

At the outset it is helpful to iterate that the use of probabilities has particular application in the civil processes whereby the position of a child above or below a specific age threshold is of importance. The use of a formal probability calculation is a step forward in the provision of age estimation data for forensic purposes. This is especially so as the probability is easily converted to a percentage. This has resonance with the non-mathematical mind. The experience of the authors in the UK has been that this simple

Table 3
Weighted Probability using n-tds as weighting factor.

A	The subject is younger than ten years and has been assigned correctly to the <10 years group
B	The subject is older than ten years and has been assigned incorrectly to the <10 years group
C	The subject is older than ten years and has been assigned correctly to the >10 years group
D	The subject is under ten years and has been assigned incorrectly to the >10 years group

Table 4

Probability subtotals for validation subjects, 50 females and 50 males, correctly or incorrectly assigned to above or below 10 years old.

Probability of study subjects being <10 years or >10 years.				
	A <10 yrs – correct	B <10 yrs – incorrect	C >10 yrs – correct	D >10 yrs – incorrect
Females	20 (40%)	2 (4%)	26 (52%)	2 (4%)
Males	29 (58%)	0 (0%)	19 (38%)	2 (4%)
Totals	49 (49%)	2 (2%)	45 (41%)	4 (4%)

It is helpful to limit this to the subtotals for females and males.

Column **A** plus Column **C** (49% + 45%) show that on 94% of assessments, the assignment of individuals to above or below the ten year threshold is correct.

Column **B** shows that only 2 children who are under ten years old are incorrectly assigned an age over ten years. This is disadvantageous to these children.

Column **D** shows that 4 children over 10 years old are deemed to be under ten years. This is to the advantage of these children although the interests of justice may not be served.

way of presenting data has been welcomed by the courts. This is very much the result of the need to present data that is fully comprehended by judge *and* jury.

There is considerable concern within the UK regarding numeracy of ‘members of the public’ and their ability to comprehend the submissions made by statisticians to the courts.¹⁰

This study is first to report the use of multiple probabilities from developing teeth in a single subject, ‘averaged’ to give an overall probability that the subject is above or below a specific threshold. For this reason, there are no data or related procedures to compare with this work. Further work is needed to test other weighting factors to determine which approach is the most reliable. Also, other age thresholds need to be explored to determine whether or not the use of probability and the concomitant percentage probability creates statistical evidence which brings into close approximation to enable the courts to arrive at an appropriate decision. That is to say a decision that is fair to the individual whose calendric status is under scrutiny.

This approach is offered as a step forward in that issue.

Appendix A. Supplementary data

Supplementary data related to this article can be found at <http://dx.doi.org/10.1016/j.jflm.2014.06.002>.

Ethical approval

None declared.

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Conflict of interest

None declared.

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