Int J Legal Med (2006) 120: 49–52
DOI 10.1007/s00414-005-0047-9

TECHNICAL NOTE

Roberto Cameriere · Luigi Ferrante · Mariano Cingolani

Age estimation in children by measurement of open apices in teeth

Received: 13 May 2005 / Accepted: 5 September 2005 / Published online: 10 November 2005

Abstract This paper concerns a method for estimating the age of children based on their teeth. The sample consisted of 455 Italian white children (213 boys, 242 girls) aged between 5 and 15 years. The purpose of the present investigation was to present a method for assessing chronological age based on the relationship between age and measurement of the open apices in teeth. Pearson's correlation coefficients between age and these variables showed that the correlations between age and the open apices in teeth were significant and negative. Furthermore, gender and the number of teeth with the apical end of the root canals completely closed (N_0) showed a significant correlation with chronological age. With the aid of a stepwise multiple regression model, a linear relationship between open apices, N_0, and age was shown. Statistical analysis indicated that these morphological variables explain 83.6% of the variations in estimated chronological age. The median of residual errors between the actual and estimated ages was −0.035 years [interquartile range (IQR)=1.18 years].

Keywords Forensic age estimation · Open apices · Mineralization · Multiple regression

Introduction

Age estimation in children is a fundamental question in forensic medicine, paediatric endocrinology and in orthodontic treatment. The most important anatomical areas for age estimation are dental and the hand-wrist area. During the growth of a person, the application of skeletal, odontological, anthropological and psychological methods allows an approximate assessment of age. Among the methods most frequently used for skeletal maturity are those concerning the left hand-wrist area (e.g., Tanner–Whitehouse [1] and FELS [2] methods), which can produce estimates up to the age of 16 years, at which time wrist maturation is complete in 90% of subjects. Other useful methods are based on radiographs of specific structures such as medial clavicular epiphysis cartilage [3, 4].

However, these skeletal methods present some drawbacks in view of the important variability of bone maturation, which is influenced by environmental factors. An alternative approach based on dental development was shown to be suitable for age determination in children because the calcification rate is controlled more by genes than by environmental factors, and this yields a lower variability [5–7].

Various odontological methods have also been carried out to estimate age, assessing eruption phases within acceptable error limits. Basically, these methods define the stages of mineralization of teeth observed in radiographs and code them according to predetermined scores.

The most common method for age estimation was published in 1973 by Demirjan, Goldstein and Tanner [8] and subsequently modified by others authors [9, 10]. Indeed, the Demirijan method offers the possibility to calculate a maturity score as a function of age and its 95% confidence interval. Therefore, this method is designed for clinicians who know the real age of the children and want to know if they deviate from the norm, to determine if their dental maturity is advanced or delayed. Since the estimates and their predictive intervals are calculated for the maturity score, this method is inappropriate for chronological age estimation [11].

Nevertheless, the Demirijan method is widely used in studies of dental maturity and for age estimation in individuals of unknown age [12, 13]. To improve this method, several authors developed alternative approaches based on

R. Cameriere (✉) · M. Cingolani
Institute of Legal Medicine,
Via D. Minzoni 9,
62100, Macerata, Italy
e-mail: r.cameriere@unimc.it
Tel.: +39-733-258215
Fax: +39-733-2582635

L. Ferrante
Institute of Biochemical Biotechnologies Faculty of Medicine,
Polytechnical University of Marches,
via Ranieri 65,
60100, Ancona, Italy

the measurement of some significant tooth parameters, such as the degree of racemization of aspartic acid in the enamel of teeth [14–16] or crown height, apex width root and pulp length of the teeth observed in radiographs [17–19].

The purpose of this investigation was to present a method for assessing chronological age in children based on the relationship between age and the measurement of the open apices in teeth. In an attempt to improve the precision and reliability of the age estimations, other dental features were also taken into account, and the different statistical models were compared.

Materials and methods

Subjects and materials

Orthopantomographs taken from 455 Italian white children (213 boys, 242 girls) aged between 5 and 15 years were analysed (Table 1). X-rays were digitized using a scanner, and images were recorded on computer files, which were processed using a computer-aided drafting program (Adobe Photoshop 7).

The seven left permanent mandibular teeth were valued. The number of teeth with root development complete, apical ends of the roots completely closed (N_0), was calculated.

Furthermore, the teeth with root development incomplete, and therefore with open apices, were considered. For teeth with one root, the distance (A_i, i=1,...,5) between the inner sides of the open apex was measured (Fig. 1). For teeth with two roots (A_i, i=6, 7), the sum of the distances between the inner sides of the two open apices was evaluated (Fig. 2). To take into account the effect of possible differences in magnification and angulation among x-rays, we normalized the measurements by dividing by the tooth length (L_i, i=1,..,7).

Finally, dental maturity was evaluated using the normalized measurements of the seven left permanent mandibular teeth ($x_i=A_i/L_i$, i=1,…,7), the sum of the normalized open apices (s) and the number (N_0) of teeth with root development complete.

All measurements were carried out by the same observer. To test intra-observer reproducibility, a random sample of 40 panoramic radiographs were re-examined after an interval of 2 weeks.

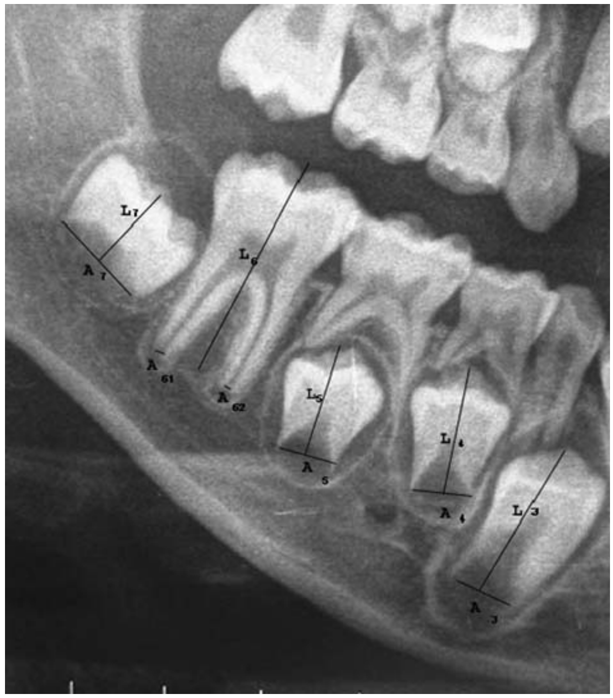

Fig. 1 An example of tooth measurement. A_i, i=1,...,5 (teeth with one root), is the distance between the inner sides of the open apex; A_i, i=6, 7 (teeth with two roots), is the sum of the distances between the inner sides of the two open apices; and L_i, i=1,...,7, is the length of the seven teeth

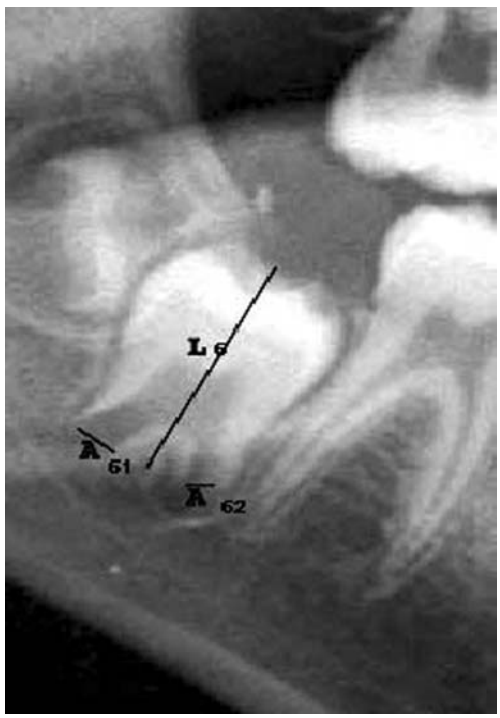

Fig. 2 An example of measurement of a tooth with two roots. A_6 is the sum of the distances ($A_6 = A_{61} + A_{62}$) between the inner sides of the two open apices, and L_6 is the length of the second molar

Table 1 Age and gender distribution of the sample studied

Age (years)	Number of girls	Number of boys	Total
6–7	25	13	38
8–9	79	59	138
10–11	69	58	127
12–13	36	46	82
14–15	33	37	70
Total	242	213	455

Table 2 Stepwise regression analysis predicting chronological age from the chosen predictors

	Value	Standard error	*t* Value	*p*
Intercept	8.971	0.223	40.16	<0.001
g	0.375	0.088	4.28	<0.001
*x*5	1.631	0.378	4.31	<0.001
N_0	0.674	0.040	17.02	<0.001
s	−1.034	0.123	−8.41	<0.001
$s{:}N_0$	−0.176	0.032	−5.41	<0.001

$s{:}N_0$ specifies the interaction between the two variables s and N_0

Statistical analyses

All the morphological variables, x_i, i=1,...,7, s, N_0, and subjects' gender, were entered in an EXCEL file for use as predictive variables for age estimation in the subsequent statistical analysis.

Chronological age, calculated by subtracting date of birth from the date of radiograph, was also recorded in the EXCEL file.

Intra-observer reproducibility of measurements was studied using the concordance correlation coefficient. Furthermore, correlation coefficients were evaluated between age and predictive variables. To obtain an estimate age as a function of the morphological variables and subjects' gender, we developed a multiple linear regression model with first order interactions by selecting those variables that contributed significantly to age estimations using the stepwise selection method. Analysis of covariance (ANCOVA) was then applied to study the possible interactions between significant morphological variables and gender. Statistical analysis was performed with S-PLUS 6 statistical programs (S-PLUS 6.1 for Windows Professional Edition Release 1). The significance threshold was set at 5%.

Results

There were no statistically significant intra-observer differences between the paired sets of measurements carried out on the re-examined panoramic radiographs. Pearson's correlation coefficients between age and morphological variables showed that all of these variables were significantly correlated with age. All correlation coefficients between age and morphological variables were significant and negative. Subjects' age was modelled as a function of the morphological variables (predictors), and to optimize the model, a stepwise regression procedure was applied.

The results (Table 2) show that gender and the variables $x5$ (second premolar), s, N_0 and the first order interaction between s and N_0 contributed significantly to the fit. Thus, only these variables were included in the regression model, yielding the following linear regression formula:

$$\begin{aligned}\text{Age} =& 8.971 + 0.375\ \text{g} + 1.631\ \text{x}\ 5 + 0.674\ \text{N}_0 \\ & -1.034\ s - 0.176\ s \cdot \text{N}_0\end{aligned} \quad (1)$$

where g is a variable equal to 1 for boys and 0 for girls.

In Eq. 1, only intercept varies with gender, and therefore, sexual dimorphism does not change with age. However, the equation points out to advanced dental maturity for girls at all ages.

This model had the lowest Akaike Information Criterion (AIC) value among the considered multiple regression

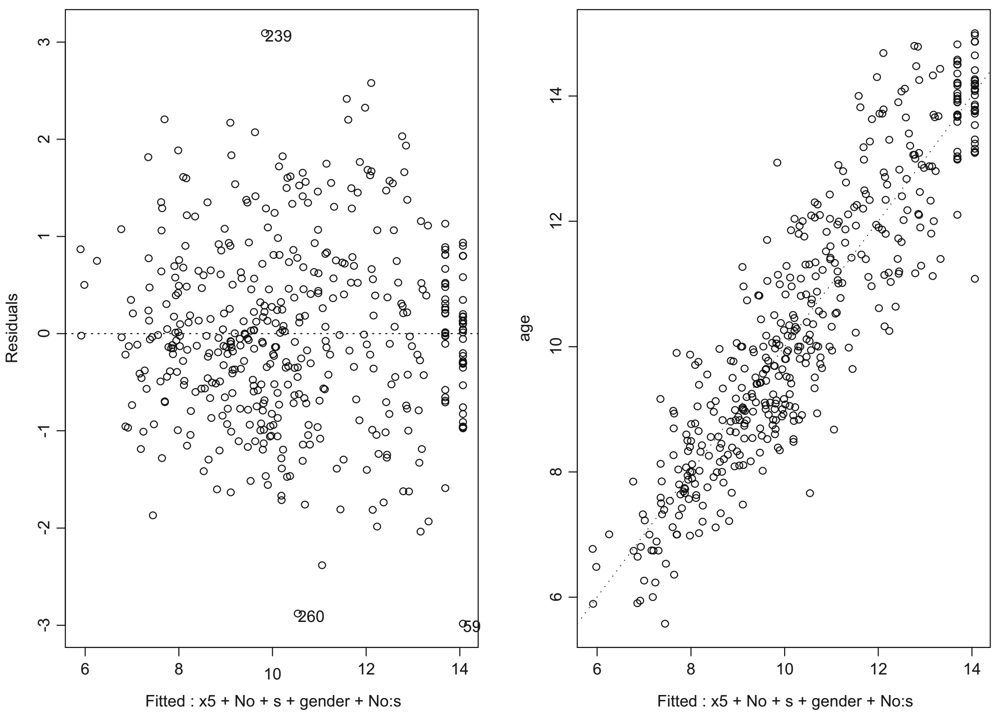

Fig. 3 Plot of the residuals against the fitted values (*left panel*) and plot of the observed against predicted values (*right panel*) by using the regression model (Eq. 1)

models, and there was a modest improvement in the model fit when all predictors were used.

Indeed, the full model explained 86.5% of total variance, whereas Eq. 1, with the selected variables, explained 83.6% (R^2=0.836). The median of the residuals (=observed age minus predicted age) was −0.035 years, with interquartile range (IQR)=1.18 years.

The residual plot (Fig. 3, left panel) shows no obvious pattern, and only three observations appeared to be possible outliers. The observed vs predicted plot (Fig. 3, right panel) shows that the regression model fits the trend of the data reasonably well. Hence, both diagnostic plots support our chosen model.

Discussion

The need to estimate the age of living individuals is becoming increasingly important in forensic odontology since there are increasing numbers of immigrants (illegal or otherwise) who arrive in a country without acceptable identification papers and, more generally, individuals with missing or uncertain birth data.

The study of the morphological parameters of teeth on dental x-rays of adult humans is more reliable than are most other methods for age estimation and is most commonly used to determine age in living humans. Several studies show that morphological measurements can be reliably made in panoramic radiography, provided that some corrections are made to take into account the individual variability of tooth size and the differences in magnification of radiographs and angulation between x-ray beam and film.

In this study, to obtain an estimated age in Italian children aged between 5 and 15 years old, we used the measurements of the open apices of the seven left permanent mandibular teeth.

When open apices were measured on digitized images of mandibular teeth, the concordance correlation coefficient showed that there were no significant intra-observer differences. Based on this result, we conclude that this technique can produce reliable and reproducible intra-observer measurements. ANCOVA showed that gender had a significant influence on age estimation and was therefore included as a factor in the model equation. All the normalized open apices showed a significant correlation with age, but only $x5$ contributed significantly to the fit, while the other teeth entered the model equation (Eq. 1) through the sum of the normalized open apices (s). Since dental development does not follow a linear progression, in the forensic context, some authors employed curvilinear functions to relate chronological and dental age. In particular, when dental maturity was evaluated using Demirjian's maturity score, third degree polynomial functions were used [20].

Our method, based on the normalized open apices of the seven left permanent mandibular teeth, employed a second degree polynomial function (Eq. 1), which showed a median of the absolute value of residual error of less than 0.04 years (median=−0.035 years, IQR=1.18 years) and a standard of estimate of 0.93 years. It is therefore comparable with other age estimation methods in children and is reasonably efficient and accurate. The present research confirms the validity of dental methods, together with other methods, for accessing biological age in a forensic context.

References

1. Tanner JM, Healy MJR, Goldstein H, Cameron N (2001) Assessment of skeletal maturity and prediction of adults height (TW3 Method). Saunders, London
2. Roche AF, Cameron Chumlea W, Thissen D (1988) Assessing the skeletal maturity of the hand-wrist: FELS method. Charles C. Thomas Publisher, Springfield
3. Schmeling A, Schulz R, Reisinger W, Muhler M, Wernecke KD, Geserick G (2004) Studies on the time frame for ossification of the medial clavicular epiphyseal cartilage in conventional radiography. Int J Legal Med 118:5–8
4. Schulz R, Mühler M, Mutze S, Schmidt S, Reisinger W, Schmeling A (2005) Studies on the time frame of ossification of the medial epiphysis of the clavicle as revealed by CT scans. Int J Legal Med 119:142–145
5. Nolla C (1960) The development of permanent teeth. J Dent Child 27:254
6. Moorres CFA, Fanning EA, Hunt EE (1963) Age variation of formation stages for ten permanent teeth. J Dent Res 42:1490
7. Gleiser I, Hunt EE (1995) The permanent mandibular first molar; its calcification, eruption, and decay. Am J Phys Anthropol 13:253–283
8. Demirjian A, Goldstein H, Tanner JM (1973) A new system of dental age assessment. Hum Biol 45:211–227
9. Chaillet N, Nystrom M, Kataja M, Demirjian A (2004) Dental maturity curves in Finnish children: Demirjian's method revisited and polynomial functions for age estimation. J Forensic Sci 49:1324–1331
10. Koshy S, Tandon S (1998) Dental age assessment: the applicability of Demirjian's method in south Indian children. Forensic Sci Int 94:73–85
11. Teivens A, Mornstad H (2001) A modification of the Demirijan method for age estimation in children. J Forensic Odontostomatol 19:26–30
12. Prieto LJ, Barberia E, Ortega R, Magaña C (2005) Evaluation of chronological age based on third molar development in the population. Int J Legal Med. DOI10.1007/S00414-005-0530-3
13. Olze A, Bilang D, Schmidt S, Wernecke KD, Geserick G, Schmeling A (2005) Validation of common classification systems for assessing the mineralization of third molars. Int J Legal Med 119:22–26
14. Ritz-Timme S, Laumeier I, Collins M (2003) Age estimation based on aspartic acid racemization in elastin from the yellow ligaments. Int J Legal Med 117:96–101
15. Othani S, Ito R, Yamamoto T (2003) Differences in the D/L aspartic acid ratios in dentin among different types of teeth from the same individual estimated age. Int J Legal Med 117: 149–152
16. Othani S, Ito R, Arany S, Yamamoto T (2005) Racemization in enamel among different types of teeth from the same individual. Int J Legal Med 119:66–69
17. Mornstad H, Staaf V, Welander U (1994) Age estimation with the aid of tooth development: a new method based on objective measurements. Scand J Dent Res 102:137–143
18. Cameriere R, Ferrante L, Cingolani M (2003) Variations in pulp/tooth area ratio as an indicator of age: a preliminary study. J Forensic Sci 49:317–319
19. Paevlinsky E, Pfeiffer H, Brinkmann B (2005) Quantification of secondary dentine formation from orthopantomograms—a contribution to forensic age estimation methods in adults. Int J Legal Med 119:27–30
20. Chaillet N, Demirjian A (2004) Dental maturity in South France: a comparison between Demirjian's method and polynominal functions. J Forensic Sci 49:1059–1066