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Age estimation in children by measurement of open apices in teeth: a European formula

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Abstract The aim of the present paper was to improve and expand research with a larger number of children from various European countries and to provide a common formula useful for all these countries. Orthopantomographs taken from 2,652 European Caucasian children (1,382 boys, 1,270 girls) aged between 4 and 16 years were analyzed. The children came from Croatia, Germany, Kosovo, Italy, Slovenia, Spain, and the UK. Following the pilot study, subjects' age was modeled as a function of gender (g), morphological variables (predictors)×5 (second premolar), s (sum of normalized open apices) N_0, and the first-order interaction between s and N_0. The results showed that all these variables contributed significantly to the fit, so that all were included in the regression model, yielding the following linear regression formula: Age$=8.387+0.282\ g-1.692\times 5+0.835\ N_0-0.116\ s-0.139\ s\times N_0$, where g is a variable, 1 for males and 0 for females. The equation explained 86.1% ($R^2=0.861$) of total deviance. The median of the residuals (=observed age minus predicted age) was −0.114 years, with (RefB.2) interquartile range=1.22 years.

Keywords Forensic science · Age estimation · Open apices · Mineralization · Multiple regression

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Introduction

Evaluation of skeletal age using radiological techniques is a suitable criterion for assessing individual biological maturation and is normally applied to answer forensic, pediatric, and orthodontic questions. Over the last century, social problems and the discovery of X-rays encouraged the study of a number of methods for age evaluation in both adults and non-adults.

In non-adult subjects, dental age is one of the major indicators of maturity and was used in the UK to estimate age in children before it became obligatory to register births in 1837. Saunders, a dentist, wrote a paper entitled "The teeth: a test of age, considered with reference to the factory children," which was addressed to the members of both Houses of Parliament [1].

After the discovery of X-rays, several methods for age estimation were studied. At present, the need to estimate the age of living individuals is a problem of increasing interest in our community, due to the progressively increasing numbers of persons without legal documentation of birth, who are suspected of having committed crimes and for whom it is necessary to assess actual age to establish imputability.

Teeth are the most frequently used part of the body analyzed for age estimation. The high number of teeth and the continuous modification of both crown and root in children mean that several methods of estimating age from teeth can be applied.

The routine use of X-rays since 1950 induced researchers to focus on mineralization. In particular, in 1973 Demirjian et al. [2] studied one method of age estimation. Their original sample comprised 1,446 boys and 1,482 girls of French–Canadian origin, and their data were later compared with other sample groups from several nationalities. Most of the results revealed the fact that the standards of dental maturation described by Demirjian et al. are not always suitable for these countries [3–7]. A few papers modified the original regression model with new samples [e.g., 8, 9], one of which assessed a large sample from eight countries worldwide [10]. Although these studies validated the method, they also highlighted the need to apply a particular regression model to each country.

In 2006, Cameriere et al. [11] presented a method for assessing chronological age in children based on the relationship between age and measurement of open apices in teeth, which gave reliable estimates of the ages of 455 Italian Caucasian children. In the same year, the same authors also published a paper with additional samples from Kosovo and Slovenia, for a total number of 1,100 children [12]. Its aim was to improve and expand research with new numbers of European children from various countries and to complete a common formula useful for all of them.

Materials and methods

Orthopantomographs from 2,652 European Caucasian healthy children (1,382 boys, 1,270 girls) aged between 4 and 16 years were analyzed (Table 1). The children came from Croatia, Germany, Kosovo, Italy, Slovenia, Spain, and the UK (Table 2). The orthopantomographs were taken as part of the routine treatment between 2000 and 2006.

Table 1 Age and sex distribution of studied individuals

Age	Females	Males	Total
4	14	15	29
5	31	55	86
6	72	77	149
7	113	117	230
8	161	161	322
9	178	174	352
10	168	180	348
11	156	154	310
12	123	153	276
13	125	137	262
14	76	90	166
15	32	40	72
16	21	29	50
Total	1,270	1,382	2,652

Table 2 Distribution of studied individuals in various countries

Country	Females	Males	Total
Croatia	120	148	268
Germany	251	249	500
Kosovo	162	164	326
Italy	232	241	473
Slovenia	147	160	307
Spain	208	254	462
UK	150	166	316
Total	1,270	1,383	2,652

Orthopantomographs were made X-rays that were unclear or which showed hypodontia, gross pathology, or previous orthodontic treatment were excluded. The chronological age of each subject was calculated by subtracting the date of the X-ray from the date of birth, after converting both to a decimal age by the method of Eveleth and Tanner [13].

X-rays were in digital form or were digitalized on a scanner, and images were recorded on computer files, which were processed by a computer-aided drafting program (Adobe Photoshop 7). The method is fully explained in Cameriere et al. [11]. Briefly, the left permanent mandibular teeth, except the wisdom tooth, were assessed, with the apical ends of the roots completely closed (N_0) and were ascertained. Teeth with incomplete root development, and therefore with open apices, were also examined. For teeth with one root, the distance A_i, i=1,...,5, between the inner side of the open apex was measured. For example, A_1 denotes the distance between the inner side of the open apex of the first incisor. 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. To take into account the effect of possible differences in magnification and angulation among X-rays, measurements were normalized by dividing by tooth length (L_i, i=1,...,7). Lastly, dental maturity was evaluated using the normalized measurements of the seven permanent left mandibular teeth (x_i=A_i/L_i, i=1,...,7), the sum of normalized open apices ($s=x_1+x_2+x_3+x_4+x_5+x_6+x_7$), and the number ($N_0$) of teeth with root development completed.

Measurements were carried out by four different observers. Assessment of intra-observer and inter-observer reproducibility was checked on an independent sample of 40 panoramic radiographs.

Statistical analysis

All the morphological variables, x_i, i=1,...,7, s, and N_0, and subjects' gender were entered in an Excel file, to be used as predictive variables for age estimation in subsequent

Table 3 Correlation coefficients between age and morphological variables

x_7	x_6	x_5	x_4	x_3	x_2	x_1	N_0	S
−0.83	−0.61	−0.80	−0.84	−0.80	−0.60	−0.49	0.91	−0.86

statistical analysis. Chronological age, calculated by subtracting the date of birth from the date of the radiograph, was also recorded.

Intra-observer and inter-observer reproducibility of measurement was assessed by the concordance correlation coefficient. Correlation coefficients between age and predictive variables were also calculated. To obtain an estimate of age as a function of the morphological variables and subjects' gender and nationality, a multiple linear regression model with first-order interactions was developed by selecting those variables that contributed significantly to age estimations using the stepwise selection method. Analysis of covariance was then applied to study 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 inter-observer and intra-observer differences between the paired sets of measurements carried out on the reexamined panoramic radiographs. Pearson's correlation coefficients between age and morphological variables showed that all of them were significantly correlated with age (Table 3).

Following the pilot study [11], subjects' age was modeled as a function of gender (g), morphological variables (predictors)×5(second premolar), s, N_0, and the first-order interaction between s and N_0. The results (Table 4) show that all the considered variables contributed significantly to the fit, so that all of them were included in the regression model, yielding the following linear regression formula:

$$\text{Age} = 8.387 + 0.282\ g - 1.692 \times 5 + 0.835\ N_0 - 0.116\ s - 0.139\ s \cdot N_0 \qquad (1)$$

where g is a variable, 1 for males and 0 for females.

When nationality was added to the predictor variables, Akaike information criterion (AIC) of the statistical model increased from AIC=2,185 to AIC=2,211, and the fit had a modest and not significant improvement from R^2=0.904 to R^2=0.905. These results indicated that nationality did not contribute significantly to age estimations, and thus, it was excluded from the set of predictor variables.

In Eq. 1, only the intercept varies with gender, and therefore, sexual dimorphism does not change with age, but the equation does indicate earlier dental maturity for girls at all ages.

Equation 1, with the considered variables, explained 86.1% (R^2=0.861) of total deviance. The median of the residuals (=observed age minus predicted age) was −0.114 years, with interquartile range, IQR=1.22 years.

The residual plot (Fig. 1, right panel) shows no obvious pattern. The observed versus predicted plot (Fig. 1, left panel) shows that the regression model fits the trend of the data reasonably well. Hence, both diagnostic plots support our chosen model.

Table 4 Stepwise regression analysis predicting chronological age from chosen predictors

	Value	Std. Error	t value	P
Intercept	8.387	0.078	107.6	<0.001
g	0.282	0.039	7.3	<0.001
$x5$	−1.692	0.118	−14.3	<0.001
N_0	0.835	0.014	61.3	<0.001
s	−0.116	0.013	−8.9	<0.001
$s\times N_0$	−0.139	0.012	−11.7	<0.001

s/N_0 interaction between variables s and N_0

Discussion

Several parties of body [14–16] and, in particular, the teeth are often used as age indicators in both biological and forensic issues [17, 18]. In 2006, Cameriere et al. [11] published a new method for age estimation using measurement of open apices in teeth. In the original paper, an Italian sample aged between 5 and 15 years was studied.

The results showed that gender and variables x_5 (second premolar), s, N_0, and the first-order interaction between s and N_0 contributed significantly to the fit, so that only these

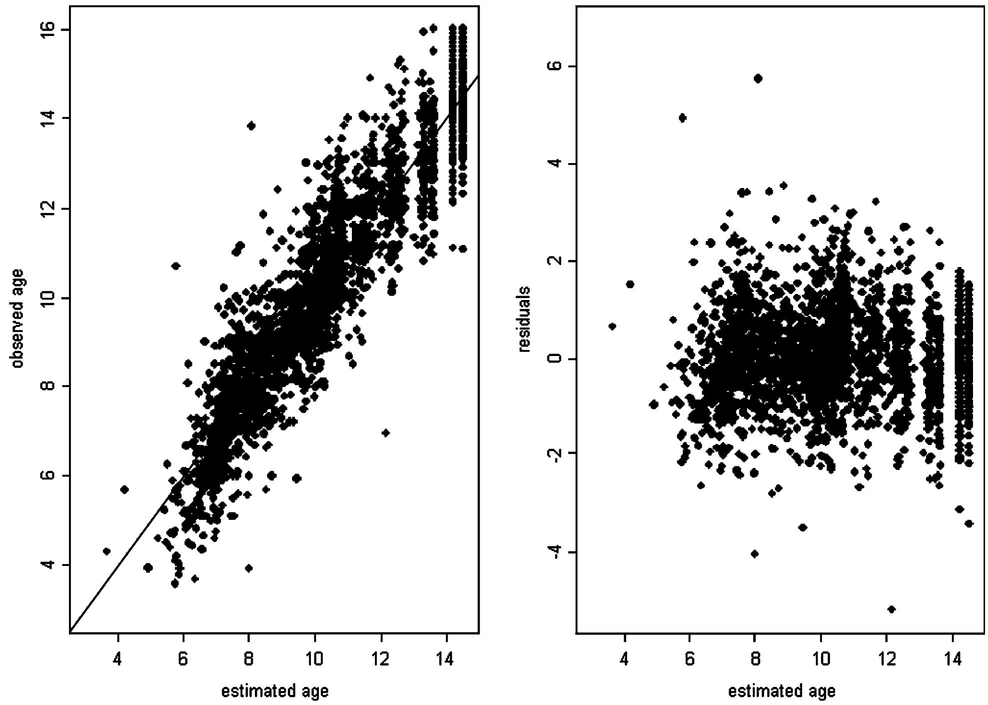

Fig. 1 Plots of residuals against fitted values (*right panel*) and of observed against predicted values (*left panel*) using regression model 1

variables were included in the regression model, yielding the following linear regression formula:

$$\text{Age} = 8.971 + 0.375\, g + 1.631\, x_5 + 0.674\, N_0 - 1.034\, s - 0.176\, s \times N_0 \quad (2)$$

Statistical analysis indicated that these morphological variables explain 83.6% of variations in estimated chronological age. The median of the absolute value of residual errors between actual and estimated ages was 0.035 years (interquartile range=1.18 years).

Larger samples from Kosovo and Slovenia were later studied. Also in this case, the similar variables contributed significantly to the fit, yielding the following linear regression formula:

$$\text{Age} = 9.063 + 0.386\, g + 1.268\, x_5 + 0.676\, N_0 - 0.913\, s - 0.175\, s \times N_0 \quad (3)$$

These morphological variables explain 83.3% of variance, and the median of the absolute value of residual error was less than 0.03 years. Therefore, the addition of new samples from other countries did not modify the parameters to any significant extent.

In the present paper, data from 2,652 European Caucasian children between 4 and 16 yielded the linear regression formula 1.

In this case, morphological variables explain 86.2% of variance, and the median of the absolute value of residual error is less than 1 year. As the results did not show any statistically significant difference between countries, one regression equation could be applied to all samples.

Data from children of the European countries added in this study increased the area to which the regression formula can be applied. The heterogeneity of the sample also suggested the possibility of using Eq. 1 for all Caucasian people, as there are no anthropological reasons for believing that it is necessary to use a different equation for European countries not included in this study. However, as soon as possible, the regression model will be compared with data from other European countries. In non-European countries, where anthropological reasons and nutritional status suggest careful study of several sample populations of Africa, America, and Asia, different issues arise.

Equation 1 will be also shown on website http://agestimation.unimc.it. If research on samples of different nationalities requires new parameter estimations, they will be re-evaluated to find a new equation with a more general validity. If that is the case, the countries involved in the estimation procedure will be mentioned on the same website to indicate clearly in which countries the proposed formula can be used.

Future research should aim at using our European sample to compare the reliability of our method with other methods for age estimations as, in particular, Willems, Demirjian, Nolla, and Haavikko [2, 19, 20].

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