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Age estimation in children by measurement of carpals and epiphyses of radius and ulna and open apices in teeth: A pilot study

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Abstract

Estimation of skeletal age using radiographic images is widely used in assessing biological growth in clinical and auxological studies. The most frequently used areas for age estimation in children and adolescents are tooth and wrist/hand, both giving good results with only a low level of radiation. This pilot study of a sample of 150 Italian children and adolescents aged between 5 and 15 years focused on analyzing the possible applications of the proportion of carpal area (Ca) and teeth mineralization as a criterion of age estimation. The regression model, describing age as a linear function of gender (g), the ratio between carpal bones area and carpal area (Bo/Ca) and the measurement of open apices, yielded the following equation:

$$\text{Age} = 4.619 + 0.401g + 0.551N_0 - 0.647s + 7.163\text{Bo}/\text{Ca} - 0.123N_0s.$$

The model explained 93% of the total variance ($R^2 = 0.93$), the median of the absolute values of residuals (observed age minus predicted age) was 0.465 years, with an inter-quartile range (IQR) equalling 0.529 years, and a standard error of estimate of 0.73 years.

Keywords: Age determination; Carpals; Teeth; Linear regression; Illegal immigration

1. Introduction

Young immigrants who arrive without documentation, are an increasing problem for European countries. The need to evaluate age to consider legal responsibility or for application of different laws for young people, require reliable methods. The maturation of several skeleton areas are studied to determine the biological age [1–3].

Skeleton maturation is an orderly process, starting with the appearance of ossification nuclei and finishing with adult bone [4]. Several methods have been studied to evaluate the correlation between biological age and chronological age using mineralization. Teeth and hand-wrist areas are the most common indicators of age in growing children. These structures were chosen to study for many reasons: the images of these bones are obtained with low level of radiation in comparison with others structures, a simple radiographic position and a significant number of bones or teeth. The most important methods to date for the hand-wrist area are Greulich–Pyle [5], TW3 [6] and FELS [7] together with Nolla [8], Demirjian et al. [9], Willems et al. [10] for teeth.

Previously Cameriere et al. have proposed a new method for age estimation using teeth [11] and hand-wrist [12]. These studies highlighted a good correlation between chronological age and mineralization.

Along the lines of the previous studies, the purpose of this investigation was to present a method for assessing chronological age in children based on the relationship between age and hand-wrist mineralization together with the measurement of the open apices in teeth.

2. Materials and methods

X-rays of wrist-hand and teeth, taken from 150 Caucasian Italian children (89 boys and 61 girls) aged between 5 and 15 years, were analyzed (Table 1). The sample was the same used for age evaluation by carpals and wrist [12], all

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Table 1
Age and gender distribution of the sample studied

Age (years)	No. of females	No. of males	Total
6–7	6	8	14
8–9	10	8	18
10–11	14	10	24
12–13	14	13	27
14–15	17	50	67
Total	61	89	150

the subjects included in the study did not display any growth disorders. All subjects were orthodontic patients and we took OPGs and hand X-rays from all of the examined patients. Both wrist-hand bones and teeth were analyzed as in the papers of Cameriere et al. [11,12].

Briefly, for wrist-hand bones, X-ray were taken of the left hand, in the postero-anterior projection, and with fingers slightly splayed. The carpal area and the epiphyses of ulna and radius were identified and the carpal area (Ca) was measured. The areas of the eight carpal bones were calculated and added together to yield the global values of bone areas (Bo). If two bones overlapped, the common area was calculated only once. Finally, to normalize the measurements, the Bo/Ca ratio between total area of bones and carpal area was calculated.

As regards teeth, the seven left permanent mandibular teeth were evaluated. The number of teeth with complete root development, i.e. apical ends of the roots completely closed (N_0), were counted.

Furthermore, the teeth with incomplete root development, i.e. with open apices, were considered and the distance (A_i, $i = 1, \ldots, 7$) between the inner side of the open apex was measured.

In order to take into account the effect of possible differences among X-rays in magnification and angulation, measurements were normalized by dividing by the tooth length (L_i, $i = 1, \ldots, 7$).

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

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.

2.1. Statistical analysis

All the morphological variables x_i $i = 1, \ldots, 7$ (the normalized measurements of the seven left permanent mandibular teeth), s (the sum of the normalized measurements of open apices), N_0 (the number of teeth with the complete root development) and Bo/Ca (ratio between total area and of bones and carpals) and subject's gender, were entered in an EXCEL file for use as predictive variables for age estimation in the subsequent statistical analysis. 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.

To evaluate the accuracy of an age estimation method, the ages of the children (Age_i, $i = 1, \ldots, n$) were compared with estimated ages ($\text{Age}_{\text{est},i}$, $i = 1, \ldots, n$) using the mean prediction error:

$$\text{ME} = \frac{1}{n}\sum_{i=1}^{n}\left|\text{Age}_i - \text{Age}_{\text{est},i}\right|,$$

where n is the number of children in the sample.

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%.

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

	Value	Standard error	T value	P
Intercept	4.619	0.594	7.771	<0.001
g	0.401	0.125	3.219	0.002
N_0	0.551	0.058	9.420	<0.001
s	−0.647	0.116	−5.577	<0.001
Bo/Ca	7.163	0.820	8.741	<0.001
sN_0	−0.123	0.048	−2.568	0.011

3. 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. 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 s, N_0, Bo/Ca and the interaction between s and N_0 contributed significantly to the fit. Thus, these variables were included in the regression model, yielding the following linear regression formula:

$$\text{Age} = 4.619 + 0.401g + 0.551N_0 - 0.647s + 7.163\text{Bo/Ca} - 0.123N_0 s \quad (1)$$

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 maturity for girls at all ages. This model had the lowest Akaike Information Criterion (AIC) value among the considered multiple regression models. Indeed Eq. (1) explained 93% of the total variance ($R^2 = 0.93$). The median of the absolute values of residuals (observed age minus predicted age) was 0.465 years, with an inter-quartile range (IQR) equalling 0.529 years. The mean prediction error, ME, was 0.553 years and a standard error of estimate was 0.73 years.

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

4. Discussion

The need to estimate the age of living individuals is becoming increasingly more important in forensic science. The judicial system often demands that a child of unknown age be assigned an age to ensure that appropriate procedures are observed in the processing of a legal case. In European countries the age threshold with regards to criminal responsibility is from a