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Accuracy of age estimation in children using radiograph of developing teeth

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Abstract

The aims of this study were: first, to determine the accuracy of the Cameriere method for assessing chronological age in children based on the relationship between age and measurement of open apices in teeth [10] and, second, to compare the accuracy of this method with the widely used Demirjian et al. method [7] and with the method proposed by Willems et al. [8].

Orthopantomographs taken from white Italian, Spain and Croatian children (401 girls, 355 boys) aged between 5 and 15 years were analysed following the Cameriere, Demirjian and Willems methods.

The difference between chronological and dental age was calculated for each individual and each method (residual). The accuracy of each method was assessed using the mean of the absolute values of the residuals (mean prediction error).

Results showed that the Cameriere method slightly underestimated the real age of children. The median of the residuals was 0.081 years (interquartile range, IQR = 0.668 years) for girls and 0.036 years for boys (interquartile range, IQR = 0.732 years). The Willems method showed an overestimation of the real age of boys, with a median residual error of −0.247 years and an underestimation of the real age of girls (median residual error = 0.073 years). Lastly, the Demirjian method overestimated the real age of both boys and girls, with a median residual error of −0.750 years for girls and −0.611 years for boys.

The Cameriere method yielded a mean prediction error of 0.407 years for girls and 0.380 years for boys. Although the accuracy of this method was better for boys than for girls, the difference between the two mean prediction errors was not statistically significant ($p = 0.19$).

The Demirjian method was found to overestimate age for both boys and girls but the mean prediction error for girls was significantly greater than that for boys ($p = 0.024$), and was significantly less accurate than the Cameriere method ($p < 0.001$).

The Willems method was better than that of Demirjian ($p = 0.0032$), but was significantly less accurate than that of Cameriere ($p < 0.001$).

Keywords: Age estimation; Teeth; Forensic odontology

1. Introduction

Several papers in the field of forensic odontology and archaeology deal with estimating chronological age in humans.

Although skeletal radiology is the most widespread method for age estimation in living subjects, modern techniques applied to adults have allowed great improvements in the X-ray processing of teeth, which are better suited for age estimations than bones [1–6].

Various odontological methods have also been applied to estimate age, assessing eruption phases within acceptable error limits [7–11]. Basically these methods define the stages of mineralization of teeth observed in radiographs and code them according to predetermined scores. However, on account of several complications, few papers have been devoted to studying their accuracy and reliability [12–16].

The aims of this study were: first, to determine the accuracy of the Cameriere method for assessing chronological age in children based on the relationship between age and measurement of open apices in teeth [10] and, second, to compare the accuracy of this method with the widely used Demirjian method [7] and with the method proposed by Willems et al. [8].

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2. Materials and methods

Orthopantomographs taken from white Italian, Spain and Croatian children (401 girls, 355 boys) aged between 5 and 15 years were analysed (Fig. 1). The origins of the sample populations (Table 1) were Italy (138 girls, 121 boys), Croatia (131 girls, 100 boys) and Spain (132 girls, 134 boys). Radiographs that were unclear or that showed hypodontia and gross pathology were excluded. The chronological age for each subject was calculated by subtracting the date of the X-ray from the date of birth, after having converted both to a decimal age according to the method of Eveleth and Tanner. The method is explained in detail in Cameriere et al. [10]. Briefly, the seven left permanent mandibular teeth were examined and the number of teeth with root development complete and with the apical ends of the roots completely closed (N_0), was calculated. Teeth with root development incomplete, and therefore with open apices, were also considered. For teeth with one root, the distance A_i, $i = 1, \ldots, 5$, between the inner sides of the open apex was measured. 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 calculated. To take into account the effect of possible differences in magnification and angulation among X-rays, measurements A_i were normalized by dividing them by tooth length L_i: $x_i = A_i/L_i$, $i = 1, \ldots, 7$. Lastly, dental maturity was evaluated using the normalized measurements of the open apices of the seven left permanent mandibular teeth, x_i, $i = 1, \ldots, 7$, their sum, s, and the number, N_0, of teeth with root development complete.

Age was also estimated by Demirjian's method using the sex-specific tables of Demirjian et al. [8] and by the method of Willems et al., which consists of adjusted scores using the tooth stages of Demirjian [9].

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 at least 2 weeks.

2.1. Statistical analysis

The accuracy of dental age estimation was defined as how closely chronological age, measured as the difference between chronological age and dental age, could be predicted. To evaluate the accuracy of an age estimation method, the age of each child (Age_i, $i = 1, \ldots, n$) was compared with estimated ages ($\text{Age}_{\text{est},i}$, $i = 1, \ldots, n$) using the mean prediction error:

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

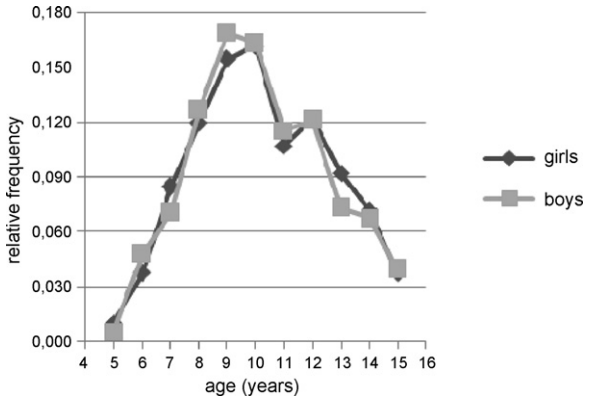

Fig. 1. Age distribution for male and female groups.

Table 1
Distribution of nationality and gender of sample studied

Country	Girls	Boys	Total
Croatia	131	100	231
Italy	138	121	266
Spain	132	134	259
Total	401	355	756

where n is the number of children in the sample, and E_i ($i = 1, \ldots, n$) is the absolute value of the ith residual, i.e., the difference between the chronological and dental ages of the ith individual:

$$\delta_i = \text{Age}_i - \text{Age}_{\text{est},i}, \quad i = 1, \ldots, n$$

Intra-observer reproducibility of measurements of the sum of the normalized open apices was studied applying the concordance correlation coefficient, and Cohen's kappa was used to measure the reproducibility for Demirjian's stages for each tooth.

The Kruskal–Wallis rank sum test was performed to test the homogeneity hypothesis in comparing the distributions of the residuals among nationalities.

The normal approximation of the Wilcoxon signed-rank sum procedure was employed to test the homogeneity hypothesis in comparing two distribution functions as for the significance of the difference between chronological and dental age. This test was performed for each method of age estimation and for boys and girls separately.

Statistical analysis was carried out by the S-PLUS 6 statistical program (S-PLUS 6.1 for Windows Professional Edition, Release 1). The significance threshold was set at 5%.

3. Results

There were no statistically significant intra-observer differences between the paired sets of measurements carried out on the re-examined panoramic radiographs. No significant differences were observed for age distribution between boys or girls ($p = 0.864$) (Fig. 1) and no significant difference were observed for the distributions of residuals among nationalities ($p = 0.100$).

The Cameriere method showed a slight underestimation of the real age of children (Table 2). The median of the residuals was 0.081 years (interquartile range, IQR = 0.668 years) for girls and 0.036 years for boys (interquartile range, IQR = 0.732 years). The Willems method showed an overestimation of the real age of boys, with a median residual error of −0.247 years and an underestimation of the real age of girls (median residual error = 0.073 years). The Demirjian method overestimated the real age of both boys and girls, with a median residual error of −0.750 years for girls and −0.611 years for boys.

The Cameriere method yielded 38.4% of absolute residuals (differences between chronological and dental ages) greater than 0.50 years and only 13.1% were greater than 1.00 years. Instead, the percentage of absolute residuals greater than 0.50 years rose to 70.9% and 66.8%, respectively, when the Demirjian and Willems methods were employed (Fig. 2).

Table 2
Median of residuals (in years), first and third quartiles and IQR for each method tested, for children aged 5–15 years

Method	Gender	Median	Q_1	Q_3	IQR
Cameriere	Girls	0.081	−0.186	0.482	0.668
	Boys	0.036	−0.290	0.442	0.732
	Both	0.059	−0.232	0.478	0.709
Demirjian	Girls	−0.750	−1.583	−0.044	1.539
	Boys	−0.611	−1.340	0.032	1.371
	Both	−0.700	−1.500	0.000	1.500
Willems	Girls	0.073	−0.790	0.757	1.547
	Boys	−0.247	−1.007	0.500	1.507
	Both	−0.072	−0.924	0.666	1.590

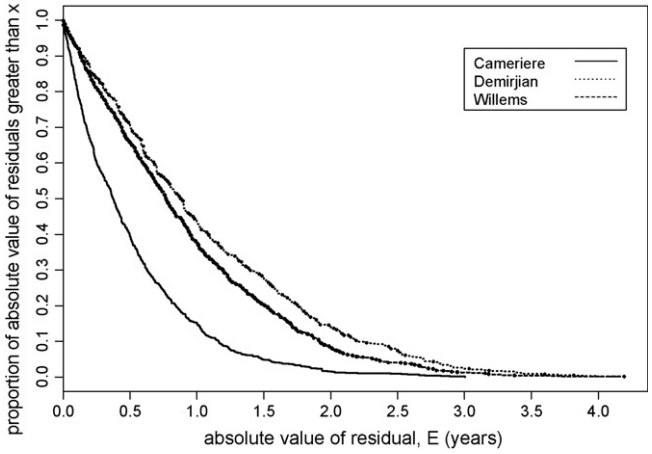

Fig. 2. Proportion of absolute residuals greater than a set value, by the methods of Cameriere, Demirjian and Willems.

Table 3
Mean prediction error (years) for each method for children aged 5–15 years

Method	Gender	*N*	Mean	S.E.	95% confidence interval
Cameriere	Girls	401	0.479	0.020	0.440–0.519
	Boys	355	0.499	0.022	0.456–0.541
	Both	756	0.488	0.015	0.459–0.517
Demirjian	Girls	401	1.133	0.042	1.051–1.216
	Boys	355	1.011	0.042	0.929–1.092
	Both	756	1.076	0.030	1.017–1.134
Willems	Girls	401	0.931	0.035	0.861–1.000
	Boys	355	0.935	0.038	0.861–1.008
	Both	756	0.933	0.026	0.882–0.983

The accuracy results are listed in Table 3. The Cameriere method yielded a mean prediction error of 0.407 years for girls and 0.380 years for boys. Although accuracy was better for boys than for girls, the difference between the two mean prediction errors was not statistically significant ($p = 0.19$).

The Demirjian method (Tables 2 and 3) was found to overestimate age for both boys and girls but the mean prediction error for girls was significantly greater than that for boys ($p = 0.024$) and was significantly less accurate than that of Cameriere ($p < 0.001$).

The Willems method was better than that of Demirjian ($p = 0.0032$) but was significantly less accurate than that of Cameriere ($p < 0.001$)

Figs. 3–5 show accuracy by method for each age cohort for boys and girls. When the Cameriere method was employed, the 15-year-old age cohort was the least accurate for both boys and girls. The Demirjian method always overestimated chronological age and yielded the worst estimates for both boys and girls at the ages of 5 and 13 years. The Willems method showed fluctuating residual errors.

4. Discussion

The ability of an age estimation method to predict chronological ages (accuracy) closely and the extent to which estimated ages remain consistent over repeated measurements of the same individual (reproducibility) are basic characteristics for every practical purpose of the method.

Although teeth were often used as age indicators for both biological and forensic issues, to the best of our knowledge, few papers have been devoted to testing the accuracy [11–15] and reproducibility [16] of age estimation methods.

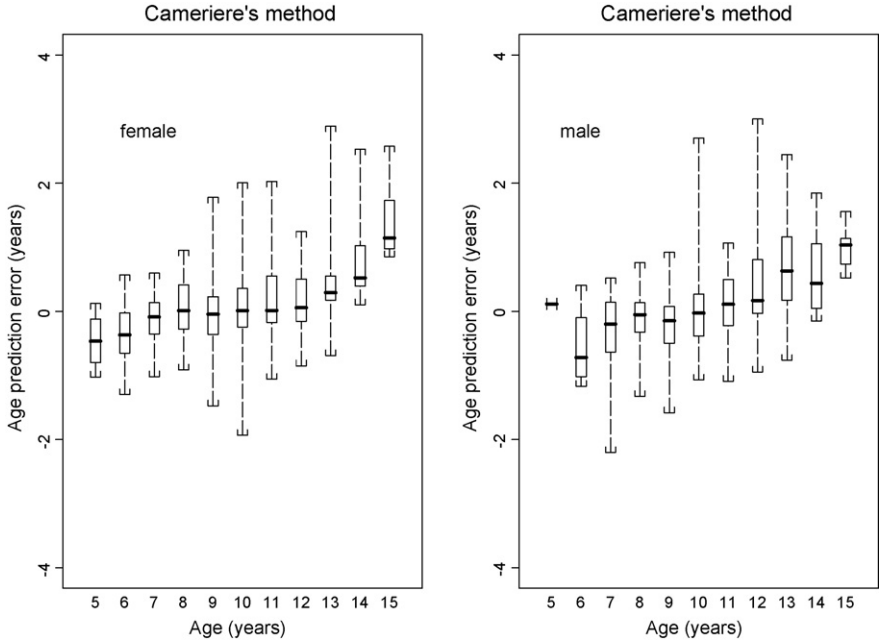

Fig. 3. Boxplots of differences between real and estimated ages by Cameriere's method (left panel; girls; right panel: boys). Horizontal lines inside boxes are located at median of data; height of boxes gives interquartile range (IQR); whiskers indicate range.

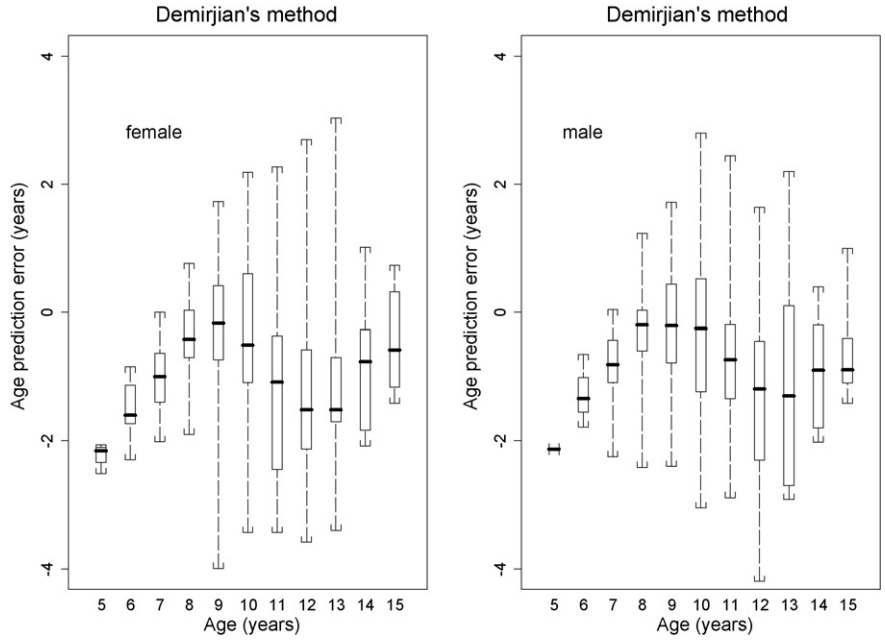

Fig. 4. Boxplots of differences between real and estimated ages by Cameriere's method (left panel; girls; right panel: boys). Horizontal lines inside boxes are located at median of data; height of boxes gives interquartile range (IQR); whiskers indicate range.

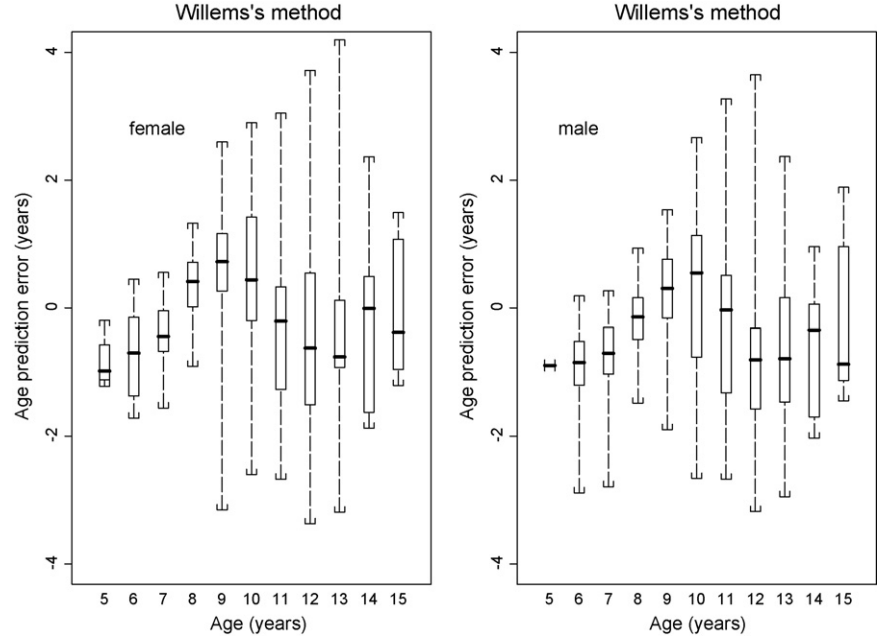

Fig. 5. Boxplots of differences between real and estimated ages by Willems' method (left panel; girls; right panel: boys). Horizontal lines inside boxes are located at median of data; height of boxes gives interquartile range (IQR); whiskers indicate range.

In this paper, we evaluated the accuracy of a new method for age estimation which measures the open apices in teeth [10]. The accuracy of estimated age is computed by mean prediction error ME.

In 2006, Maber et al. compared various methods of age estimation using developing teeth: modifications of Demirjian's method by Demirjian, Nolla, Haavikko and Willems.

The results highlighted the fact that the most accurate method was that of Willems, followed by Demirjian, which also turned out to be the easiest and clearest method. For this reason, and for its extensive use in both forensic odontology and studies of dental maturity, we compared the accuracy of the Cameriere method with those of Demirjian and Willems.

According to previous findings [17–21], the Demirjian method overestimates age for both boys and girls and is significantly less accurate than the Cameriere method. The Williams method also turned out to be less accurate than that of Cameriere.

According to previous findings [10] that age in younger children can be more accurately predicted than in older children using the Cameriere method, the least accurately estimated age, for both boys and girls, was the 15-year-old cohort (ME = 1.14 years for girls, 1.036 years for boys). The significant decrease in accuracy in the oldest age cohort depends on many variables, but may particularly be attributed to the almost complete maturation of the teeth in this age cohort.

More than 90% of the absolute value of residual errors obtained using the Cameriere method was less than 1 year.

In conclusion, results indicate the suitability of the sum of normalized open apices (s) and number (N_0) of teeth with complete root development as developmental markers, especially when comparing the resulting accuracy with other methods of age estimation (developing teeth or skeletal age calculation techniques, based on radiographs of specific structures such as the medial clavicular epiphyseal cartilage).

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