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Research Paper

Effectiveness of three age estimation methods based on dental and skeletal development in a sample of young Brazilians

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ABSTRACT

Objective: This study compared three methods designed for age estimation.
Methods: A sample of 468 radiographs (234 panoramic and 234 carpal radiographs) collected from patients ranging from 5 to 14 years old (mean age: 11.27 years old ± 2.27 years) was used. Three age estimation methods: were applied: one founded on dental development, one founded on hand and wrist development, and a method combining both measurements. For each method, the mean error (ME), mean absolute error (MAE), root mean square error (RMSE), and mean percentage of absolute error (MPAE) were quantified. The methods: were compared based on their effectiveness for estimating age in relation to sex and age range.
Results: The data show that the method exclusively using the development of the hand and wrist had the highest error rates (ME: 1.28 M, 1.85F; MAE: 1.64 M, 1.96F; RMSE: 1.94 M, 2.32F) for both males (M) and females (F). In males, the method combining dental and skeletal development obtained outcomes that were slightly better than the method founded on only dental development (MPAE: 6.99% and 7.47%, respectively). In females, the opposite result was observed (MPAE: 8.48% and 6.59%, respectively). The method founded exclusively on skeletal development significantly overestimated ($p = 0.001$) the age (mean chronological and estimated ages: 11.27 and 12.88, respectively).
Conclusion: The methods involving dental development provided more accurate age estimates of chronological age. The method exclusively based on hand and wrist development resulted in outcomes that were highly discrepant from the chronological age.

1. Introduction

Age estimation became an essential tool in routine forensic services due to increases in sexual violence, illegal immigration, and mass disasters (Cericato, Franco, Bittencourt, Nunes, & Paranhos, 2016; Franco, Thevissen, Fieuws, Souza, & Willems, 2013). From an anthropological point of view, age estimation enables the reconstruction of a biological profile of the victim and can be combined with information related to sex, stature, and ancestry (Senn & Weems, 2013). One method of age estimation uses analyses of dental and skeletal development (Cericato, Bittencourt, & Paranhos, 2015). This approach is useful for estimating the age of children and adolescents because several teeth and bones develop in parallel during childhood (Thevissen, Kaur, & Willems, 2012).

Several previous studies have developed and validated age estimation methods for different populations to test the effectiveness of age estimation (Alsaffar et al., 2017; Fernandes et al., 2011; Franklin et al., 2016; Guo et al., 2014; Kanchan-Talreja, Acharya, & Naikmasur, 2012; Mohd Yusof, Cauwels, & Martens, 2015). A combination of several parameters related to age can increase the accuracy in age estimation (Cameriere, Ferrante, Ermenc, Mirtella, & Strus, 2008; Fieuws et al., 2016; Thevissen et al., 2012) and can retrieve more age-related information from a person. Previous studies by Cameriere, Ferrante, Cingolani (2006), Cameriere, Ferrante, Mirtella, and Cingolani (2006),

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and Cameriere and Ferrante (2008) designed methods for age estimation based on 1) dental and 2) hand and wrist development, exclusively or 3) in combination. The methods were calibrated in Italian populations and consisted of mathematical calculations that expressed the age through the application of formulae (Cameriere & Ferrante, 2008; Cameriere, Ferrante, Cingolani, 2006; Cameriere, Ferrante, Mirtella, et al., 2006). During the past decade these methods were tested and validated worldwide (Fernandes et al., 2011; Rivera et al., 2017; Issa, Burhan, Nawaya, & Massouh, 2017). In Brazil, they are used in Medicine and Dentistry to estimate the dental and bone development for clinical and forensic purposes. However, their effectiveness was never compared within a Brazilian sample.

Testing the effectiveness of these methods is an important step prior to application in practice. The present study aimed to compare the effectiveness of three age estimation methods proposed by Cameriere, Ferrante, Cingolani (2006), Cameriere, Ferrante, Mirtella, et al. (2006), Cameriere et al. (2008) within a cohort of Brazilian children and adolescents.

2. Material and methods

This research study was approved by the local Committee of Ethics in Human Research under the protocol number 01515012.5.0000.5418. All the procedures performed in this study complied with the Declaration of Helsinki.

The research consisted of an analytical-observational study. A sample of 468 radiographs was collected retrospectively from a database of 5500 medical records stored in a public university in Brazil. Half of the sample (n = 234) consisted of panoramic radiographs, while the other half (n = 234) consisted of carpal radiographs. The radiographs were taken from two-hundred thirty-four subjects (126 females and 108 males) for orthodontic purposes. The subject sets consisting of one panoramic and one carpal radiograph were obtained in the same day. It is important to note that no carpal or panoramic radiographs were taken for research purposes in any of the subjects. The subjects included in the sample ranged from 5 to 14 years old (mean age: 11.27 years old, standard deviation: 2.27). The inclusion criteria for sampling consisted of subjects aged below 14 years old. The exclusion criteria consisted of odontogenic or skeletal anomalies detectable in the radiographs, radiographs with poor image quality, and any history of metabolic or systemic disorders. The final sample was divided into 5 groups based on age range (Table 1).

The radiographs were taken using an analog panoramic device and were then scanned individually on a flatbed device and stored in 300dpi. A personal computer was used to import the images into Adobe Photoshop CS6 (Adobe Systems, San José, California, USA). The image analysis was performed at 100% magnification. A single examiner performed the analyses. There were ninety-four radiographs (47 panoramic and 47 carpal radiographs; nearly 20% of the sample size) re-analyzed randomly (www.random.org) 14 days after the first analysis to assess examiner reproducibility. To avoid visual fatigue, the maximum number of radiographs analyzed per day did not exceed 40. The seven mandibular left permanent teeth in the panoramic radiographs were analyzed according to Cameriere, Ferrante, Cingolani (2006). The

Table 1
Sample distribution on age range and sex.

Groups	Age Range	n	F	M
Group 5–6	5 years and 0 days to 6 years and 364 days	10	7	3
Group 7–8	7 years and 0 days to 8 years and 364 days	39	20	19
Group 9–10	9 years and 0 days to 10 years and 364 days	46	23	23
Group 11–12	11 years and 0 days to 12 years and 364 days	76	40	36
Group 13–14	13 years and 0 days to 14 years and 364 days	63	36	27

n = F + M; F: females; M: males.

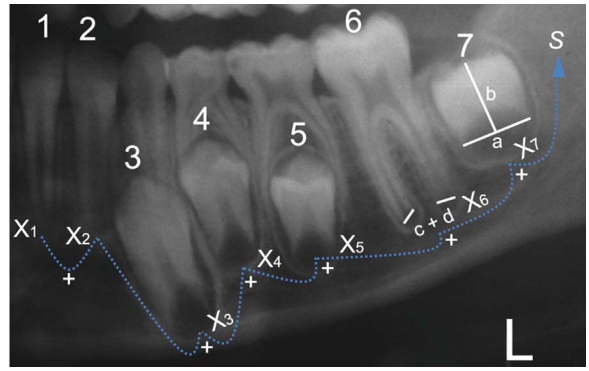

Fig. 1. Schematic illustration on the quantification of age estimated with the method proposed by Cameriere, Ferrante, Cingolani (2006) in a panoramic radiograph of a boy aged 8 year old.
Caption: Ratios (X) between the measurements of the open apexes (a) and the height (b) of the seven mandibular left (L) permanent teeth (from 1 to 7) were taken. Measurements of the two apexes (c + d) were taken in teeth with two roots. According to Cameriere, Ferrante, Cingolani (2006), the following formula was used: $age = 8.971 + 0.375\,g + 1.631 \times 5 + 0.674\,N_0 – 1.034\,s - 0.176\,s\,N_0$, in which "g" stands for males (g = 1) or females (g = 0); N_0 for the number of teeth with closed apexes; and "s" for the sum of all ratios performed in teeth with open apexes ($X_1 + X_{2+...}X_7$).

analysis was conducted from the central incisor to the second molar (Fig. 1) and excluded deciduous teeth and third molars. The bones and epiphyses of the hand, radius, and ulna of the left hand were analyzed in the carpal radiographs (Cameriere, Ferrante, Mirtella, et al., 2006) (Fig. 2). According to each method (Cameriere & Ferrante, 2008; Cameriere, Ferrante, Cingolani, 2006; Cameriere, Ferrante, Mirtella, et al. 2006), specific formulas were used to reach the estimated age.

Student's *t*-test for paired samples was used to investigate the systematic error associated with examiner reproducibility. Dahlberg (1940) formula ($error = \sqrt{\Sigma d^2/2n}$) was applied for quantifying the casual error. This formula considers the difference between the first and second analyses ("d") and the number of radiographs re-analyzed ("n"). The differences between the chronological age and the estimated age were quantified as errors (error = chronological age − estimated age) and as mean errors (ME), mean absolute errors (MAE), root mean square errors (RMSE), and the mean percentage of absolute errors (MPAE). Student's *t*-tests for paired and independent samples, as well as ANOVA, were applied to compare the estimated and chronological ages. All statistical tests were performed at a significance level of 5% ($p \leq 0.05$) using the SPSS 17.0 (IBM, Armonk, New York, USA) software package.

3. Results

The examiner reproducibility resulted in no statistically significant differences between the analyses in panoramic and lateral cephalometric radiographs.

Table 2 shows the years for ME, MAE, RMSE, and the MPAE (%) for each of the age estimation methods. The ME varied between 0.21 and 1.28 years in males and between −0.16 and 1.85 in females. The MAE varied between 0.74 and 1.64 in males and 0.73 and 1.96 in females. The RMSE in males ranged from 0.92 to 1.94, while in females, the range was 0.92 to 2.32. The highest MPAE was observed in the method based exclusively on the development of the hand and wrist (Cameriere, Ferrante, Mirtella, et al., 2006) both in males (16.09%) and females (19.40%).

Table 3 shows the outcomes for comparisons between chronological and estimated ages considering the dental development exclusively. The males and females were analyzed separately, and the results show the highest differences in the age range of 13–14 years old ($p < 0.05$). Table 4 indicates the outcomes comparing ages for the analysis of skeletal development. There were statistically significant differences