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Research Paper

Correlating skeletal and dental developmental stages using radiographic parameters

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ABSTRACT

The demand for age estimation of living and deceased children considerably increased in the last years. It was mainly justified by the growing globalization trend and the enlarged amount of violent crimes involving young victims. The present research aims to correlate skeletal and dental developmental stages using radiographic parameters. Lateral cephalometric (n = 576) and panoramic (n = 576) radiographs taken in the same moment were used to asses skeletal and dental development according to the methods of Hassel and Farman (1995) and Bacetti et al. (2002), and Demirjian et al. (1973), respectively. Likelihood-ratio test was used to verify the positive prediction in correlations between developmental stages. Spearman's correlation coefficient was calculated between skeletal and dental developmental stages, as well between estimated and chronological ages. Higher prediction in correlation for the skeletal starting stage (stage 1) with stage E in mandibular canines, and with stage D in mandibular premolars and second molars was detected. Higher staging correlations were observed considering the mandibular left second premolar (0.652, $p < 0.001$ for the technique of Bacetti et al.; and 0.646, $p < 0.001$ for the technique of Hassel and Farman). Despite the correlations between skeletal and dental developmental stages, the results must be carefully interpreted once it reached moderate values (<0.652). Further researches must test different classifications of skeletal and dental development, in order to verify the possibility of replacing one technique for another with stronger correlation.

1. Introduction

Human age estimation in young subjects became an important task in the forensic field considering that crimes against children reached an epidemic panorama, especially child sexual abuse in developing countries.[1] In certain circumstances living or deceased young victims undergo age estimation procedures quested by the Courts in order to verify if they are aged above or below the threshold of sexual consent.[2] On the other hand, suspects also may be examined for age estimation, which threshold of interest is based on the age majority.[3] Both the age of sexual consent and majority vary according to the specific Law systems. In general, the first ranges around the age of 14 or 16 years, and the second around 18 years.[2]

Several anatomic structures are developing up to 18th year of age, becoming source of age-related information for both the described legal thresholds. The most commonly used structures in the forensic routine are the human teeth[4–7]; hand-wrist bones[3]; clavicles[8] and cervical vertebrae,[9] which are generally registered in panoramic, carpal, chest, and lateral cephalometric radiographs, respectively. The human teeth reveal more advantages compared to the skeleton, once it is less influenced by intrinsic and extrinsic variables,[2] such as endocrinological disorders and environmental alterations.

The scientific literature suggests that all the possible dental and skeletal age estimation techniques should be applied for more reliable outcomes.[10] Based on that, the present research aimed to

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explore the combination of age-related anatomic structures correlating the dental and skeletal development, using radiographic parameters of the seven lower left permanent teeth and the cervical vertebrae.

2. Material and methods

The present analytical observational study was approved by the local Committee of Ethics in Research under the protocol number #382.475/2013, assuring ethical and legal standards.

The sample consisted of male (n = 262; 45.49%) and female (n = 314; 54.51%) individuals (n = 576) aged between 7 and 18 years old (mean = 12.82). From each individual a set of 1 lateral cephalometric and 1 panoramic radiograph taken at the same day was obtained. A total of 1152 radiographs (576 panoramic and 576 lateral cephalometric) were retrospectively collected from a initial database of 9000 images. The sample collection followed sample size calculation considering the absolute accuracy of 4 and significance level of 5%. All the radiographs were taken in a private Radiology clinic by a single trained operator, following diagnostic or therapeutic requests.

The exclusion criteria consisted of radiographs with low quality, including errors in image acquisition or processing; radiographs not showing the cervical vertebrae C2, C3, and C4; patients with dental agenesis, visible pathologies, history of growth disorder, absence of mandibular permanent teeth, endodontic treatment in the mandibular teeth, and with orthodontic appliances. The inclusion criteria consisted of patients aged between 7 and 18 years old, following similar sampling criteria of previous studies.[11–14]

Each set of panoramic and cephalometric radiograph from the same patient was masked receiving a sequential code number. Skeletal development was assessed within the cervical vertebrae using the methods of Hassel and Farman,[15] and Bacetti et al.[16] The dental development was assessed using the method proposed by Demirjian et al.[17] Demirjian's staging technique was not only used in the mandibular left permanent teeth, but also in the contralateral teeth allowing for left and right side comparison. In both sides the teeth staged were the canines and first and second premolars and molars. A single examiner performed the analysis. Intra- and inter-examiner reproducibility was assessed re-analyzing 33% of the sample according to Hassel and Farman[15] (n = 190), Bacetti et al.[16] (n = 190), and Demirjian et al.[17] (n = 190) within a time interval of 30 days from the initial analysis.

Stata® 12 (StataCorp® LP, Texas, USA) software was used for statistical analysis. The relations between cervical vertebrae maturation stages, by both methods, and dental development stages were assessed through absolute and relative frequencies. The Likelihood-ratio test was used as linear regression for two models to verify the ability for positive prediction between cervical vertebrae maturation stages and dental development stages. Specifically, in this test higher outcomes (close to 100) indicate a higher probability of a correct hypothesis. Spearman's correlation coefficient was calculated to statistically assess the relations between chronological age, maturation stages of cervical vertebrae, and dental development stages, as well the relation between methods. A significance level of 5%[18] was used in all of the tests. Kappa test[19] was used for calculating intra- and inter-examiner reproducibility. These results were interpreted according to the classification proposed by Landis and Koch.[20]

3. Results

The comparison between skeletal and dental developmental stages are shown from Tables 1–4, in which the outcomes according to Hassel and Farman[15] are compared with Demirjian's[17] considering the mandibular left (Tables 1 and 2) and right (Tables 3 and 4) permanent teeth.

When the Likelihood-ratio test was applied it was observed that the highest values were found in stage 1 (start) of the cervical vertebrae development, considering that dental development stages with higher values varied according to the group of teeth, such as stage E for the mandibular canine and premolars; stage F for first mandibular molars, and stage C for the mandibular second molar, regardless of the stage of cervical vertebrae development.

More specific, the present study indicates that for both skeletal age estimation methods stage 1 of cervical vertebrae development matched stages D, E, and F of dental development considering mandibular canine and premolars (with predominance of stage D); stages F and G considering the mandibular first molar; and stages C, D, and E considering the mandibular second molar. Stage 2 of cervical vertebrae development matched stages F and G considering the mandibular canine; stages E, F, and G considering mandibular premolars; stage G considering the mandibular first molar; and stages D, E, and F considering the mandibular second molar. Stage 3 of cervical maturation matched stages G and H mandibular considering the canine; stages F, G, and H considering the mandibular premolars; stages G and H considering the mandibular first molar; and stages E, F, G, and H considering the mandibular second molar. For stage 4 of cervical vertebrae development, stage H was predominant considering all the assessed teeth, except considering the mandibular second molar which matched stages G and H. For stage 5, stage H was predominant considering all the teeth.

Correlation outcomes ranged from 0.415 – for the mandibular first molar, to 0.646 – for the mandibular second premolar, using the method of Hassel and Farman.[15] With the method of Bacetti et al.[16] the correlation outcomes ranged between 0.419 and 0.652 for the mandibular first molar and the mandibular second premolar, respectively. All the correlations were statistically significant ($p < 0.001$). The correlation between both methods used for skeletal age estimation was 0.982 ($p < 0.001$). When compared to the chronological age the method of Hassel and Farman[15] reached 0.734; while Bacetti et al.[16] reached 0.730 ($p < 0.001$) (Table 5).

For both the skeletal and the dental developmental staging examiner reproducibility reached >0.91 (intra-) and >0.85 (inter-), suggesting optimal agreement.

4. Discussion

Age estimation consists on a procedure performed to assess a biological profile of victims and suspects of crimes,[10] as well as to guide legal investigations on the civil scenario.[10] The legal demand for age estimation became more common in the last years, justified by the increase in globalization[2,7] and violent crimes, especially against children.[1] Most of the age estimation techniques for young individuals are founded on the radiographic morphology of anatomic structures,[10] such as teeth[4–7] and cervical vertebrae.[9] Currently is known that more anatomic structures available result in more reliable age estimation outcomes.[10] The present study aimed to associate the developmental stages of cervical vertebrae and teeth using lateral cephalometric and panoramic radiographs, respectively.

Both the cervical vertebrae and the human teeth were already used in previous studies,[9,21] which combined developmental parameters towards the optimization of age estimation outcomes. In specific, the implementation of cervical vertebrae development, assessed through the technique of Bacetti et al.[16] in the third molars age estimation procedure performed using Köhler et al.[22] resulted in great improvement of outcomes for the early phase of dental development.[9] Considering that third molars have early