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Correlations between morphology of cervical vertebrae and dental eruption

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Abstract

The process of dental eruption is submitted to physiological and pathological variables. A series of discrepancies may occur, one of these being a disturbance between dental age and bone age. The assessment of bone age is best made with the cervical vertebral maturation (CVM) method, simplified by Baccetti *et al.* (2005). The sample studied consisted of 215 orthodontic patients. The dental age was assessed on the orthopantomograph radiographies and the bone age on the lateral cephalograms. For determining the bone age, CVM method was used. Considering dental age, most of the patients (50.2%) have a premature dental age compared to bone age, while patients with normal dental age (27.9%) and patients with late dental age (21.9%) have a lower frequency. The correlation between the dental age and the bone age of the patients shows that patients who have higher values of dental age also have higher values of bone age ($p<0.001$). The correlation between genders shows that female patients tend to have a higher average value of bone age in comparison to male patients ($p<0.001$). The authors conclude that assessing bone age based on the morphology of cervical vertebrae and correlating it with the dental age could be of great use in opting for a certain orthodontic treatment plan.

Keywords: bone age, dental age, morphology of cervical vertebrae, orthodontic patients.

Introduction

Many studies investigating the physiological dental eruption mechanisms, as well as the pathological aspects of the eruption process have been carried out. Research has not always been conclusive, a unanimous opinion on the mechanisms of dental eruption needing yet to be formulated [1]. A number of studies support the need for further investigations and clarifications in cases with dental alveolar ankylosis, primary failure of eruption (PFE), dental impaction, secondary retention, local causes that produce disturbances of the dental eruption process, such as an imbalance between bone resorption and formation, the lack of space in the dental-alveolar arch, but especially the genetic causes of the dental eruption [2, 3]. Recent genetic research has highlighted that the gene involved in the dental eruption is located on the parathyroid hormone-1 receptor (*PTH-1R*), which is responsible for familial cases with PFE [2, 4, 5]. The genetic paradigm of dental eruption is also supported by the correlation between *PTH-1R* and parathyroid hormone-related protein (PTH-rP), a gene responsible for bone remodeling on the animal model [2, 6, 7]. Clinical differential diagnosis between dento-alveolar ankylosis and PFE is often impossible in the absence of any information about previous traumas, periodontal space obliteration, and medical history or *PTH-1R* gene mutations [8, 9]. Other studies indicate the fact that the circadian rhythm of the eruption is correlated with fluctuations of the hormonal levels, which influence bone and periodontal ligaments metabolic activity [10].

On the other hand, dental eruption discrepancies can be analyzed by reference to the chronological age or to the bone age of the child or adolescent. Dental malpositions are most often the result of dental eruption discrepancies. Another category of eruption discrepancies is the occurrence of gaps between the dental eruption process and the degree of bone development of the patient. Dental eruption discrepancies, as well as malocclusions, may affect smile attractiveness and produce psychosocial disorders related to dento-facial aesthetics in terms of low self-esteem. Also, they may cause disorders of oral functions (such as chewing, swallowing or speech) [11, 12].

Franchi *et al.* (2000) propose an improved version for assessing bone development based on cervical skeletal maturation, bone age assessment being found on an analysis of the morphological maturity of cervical vertebrae using lateral cephalograms [13]. The respective authors evaluated the maxillary and mandibular growth stage in relation to the CVM, a useful tool for planning the orthodontic treatment [13, 14]. Baccetti *et al.* proposed in 2005 a simplified and improved version of the CVM method, in order to allow the optimal choice of momentum for orthodontic and dentofacial orthopedic treatment [15].

Aim

The aim of this research was to analyze a number of correlations between the dental age and the bone age of children and adolescents.

Materials and Methods

The sample consisted of 300 patients, aged between 8–14 years, in the North-West of Romania. From these, about 1/3 have been excluded. Exclusion criteria are

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represented by: patients with genetic syndromes, dento-alveolar ankylosis (evidenced by orthopantomography), patients with suspicion of PFE (taking into account the patient's medical and family history and, in some cases confirmation of the absence of PFE by *PTH-1R* genetic test), local causes (such as obstacles on the eruptive tract of the tooth), poor quality of the orthopantomographies and of the lateral cephalograms. After applying the exclusion criteria, 215 patients remained, out of which 69 were males and 146 were females, all diagnosed with dental eruption discrepancies. The study was conducted in accordance to the *World Medical Association (WMA) Declaration of Helsinki – Ethical Principles for Medical Research Involving Human Subjects*, approved by the Ethics Committee of the University of Oradea, Romania. All patients were included in the study with their parents' consent.

To analyze the frequency of dental rhythm discrepancies, the authors used the patients' orthopantomography analysis (Figure 1) and for the assessment of the bone development stage, the analysis of the stage of development of the cervical vertebrae of the patients was used, a method improved by Baccetti *et al.* (2005) [15].

Figure 1 – *Orthopantomography used for assessing the patient's dental age.*

Two investigators performed the assessment independently. According to the Baccetti *et al.* method, cervical vertebral maturation (CVM) analysis is possible using the patient's lateral cranial radiography, also known as the lateral cephalogram. The method uses the radiological analysis of C2, C3, C4 cervical vertebral morphology to assess bone age [15]. This method takes into account the presence or absence of the basal concavity at C2, C3 and C4, and the morphology of C3 and C4 vertebrae, which may take the following forms, depending on the bone development stage: horizontal rectangular, square, vertical rectangular. These evaluations allow the assessment of the patient's bone age based on the six stages of development of cervical vertebrae identified by Baccetti *et al.* (2005) [15]: CS1, CS2, CS3, CS4, CS5, CS6. For example, in CS3 stage, considered to be the pubertal growth peak, C2 has a clear concavity, while C3 and C4 have a morphological aspect of horizontal rectangular (Figure 2).

According to Baccetti *et al.* (2005), CS1 stage corresponds to the chronological age of 104.67 months (roughly 8 ½ years), CS2 stage corresponds to the chronological age of 116.4 months (roughly 9 ½ years), CS3 stage corresponds to the chronological age of 128.73 months (roughly 10 ½ years), CS4 stage corresponds to the chronological age of 141.17 months (roughly 11 ½ years), CS5 stage corresponds to the chronological age of 153.3 months (roughly 12 ½ years), and CS6 stage corresponds to the chronological age of 166 months (roughly 13 ½ years) [15].

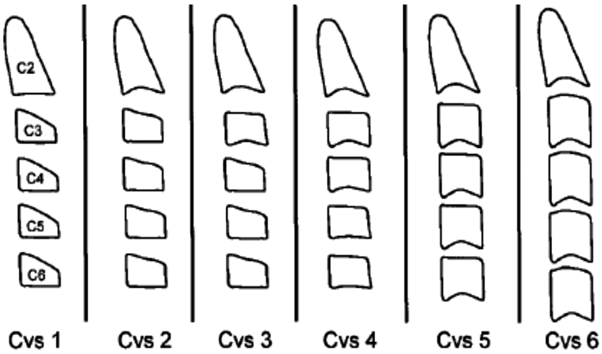

Figure 2 – *Morphological aspects of the different developmental stages of cervical vertebrae (after Franchi et al. [13]). Cvs: Cervical vertebral stage.*

Considering the information presented above, we correlated the stages of bone development with the stages of dental eruption, depending on the teeth erupted in the oral cavity, this evaluation being done, as we already mentioned, using orthopantomography.

Patients who had discrepancies of ±6 months between the dental age and the bone age were considered to have a physiological dental eruption, respectively patients with normal dental age.

For the CVM analysis, the authors utilized computerized defalcation software, entitled OnyxCeph [open software license (OSL), version 62]. In order to obtain a good morphological assessment of the vertebrae, this software requires the exact position of the following points on the lateral cephalogram (Figure 3):

- C3ua, which is the most superior point of the anterior border of the body of the C3 cervical vertebra;
- C3lp, which is the most posterior point on the lower border of the body of C3;
- C3la, which is the most anterior point on the lower border of the body of C3;
- C3pm, which is the midpoint of the posterior contour of C3 intersection of a parallel to the base line through the midpoint of the anterior outline and the posterior outline of the body of cervical vertebra;
- C4ua, which is the most anterior point of the anterior border of the body of the C4 cervical vertebra;
- C4lp, which is the most posterior point on the lower border of the body of C4;
- C4la, which is the most anterior point on the lower border of the body of C4;
- C4pm, which is the midpoint of the posterior contour of C4 intersection of a parallel to the base line through the midpoint of the anterior outline and the posterior outline of the body of the fourth cervical vertebra;
- C4ms, which is the midpoint of the superior contour of C4 intersection of a perpendicular to the base line through its midpoint and the superior outline of the body of the fourth cervical vertebra.

All the data from the study was analyzed using IBM Statistical Package for the Social Sciences (SPSS) ver. 20. Quantitative variables were tested for normal distribution using the Shapiro–Wilk test and were written as averages with standard deviations, while categorical variables were written as counts or percentages. Quantitative variables were tested using Mann–Whitney *U*-test or Kruskal–Wallis *H*-test because of their non-parametric distribution and all existent correlations were demonstrated using Spearman's rank-order correlation, while categorical variables were tested using Pearson χ^2 (chi-square) test and all existent correlations were demonstrated using Pearson correlations.

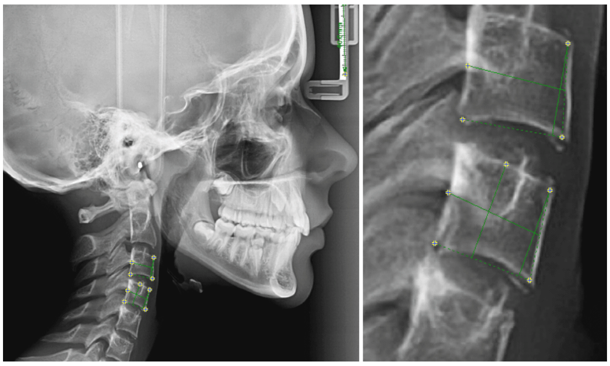

Figure 3 – *CVM analysis using OnyxCeph software on a cephalometric radiography. CVM: Cervical vertebral maturation.*

Results

The patients included in the study were divided into three groups, according to the categories of the dental age compared to the bone age. Patients who had an advance of the dental age compared to the bone age of at least six months were considered patients with premature dental age. Patients who had a physiological dental eruption explained by the difference between the dental and bone age of ±6 months were considered patients with normal dental age. Patients with a delay of the dental compared to the bone age of at least six months were considered patients with late dental age. Most of the patients included in this study (50.2%) have a premature dental age compared to bone age, patients with normal dental age (27.9%) and patients with late dental age (21.9%) have a lower frequency, as shown in Table 1 and Figure 4.

Table 1 – *Distribution of the patients according to dental age*

Dental age	No. of cases	Percent
Premature	108	50.2%
Normal	60	27.9%
Late	47	21.9%

Furthermore, by analyzing the chronological age and the bone age of the patients, a significant and positive high-grade correlation was detected using the Spearman's rank-order correlation coefficient (p<0.001, R=0.514) between the bone age and the chronological age of the patients, which shows that patients who have higher values of bone age also have higher values of chronological age, as shown in Figure 5.

We decided to also analyze the dental age and the bone age. Shapiro–Wilk test was used to determine the normality of the two parameters investigated and, in both cases, results show that the distribution was non-parametric (p<0.001). Furthermore, a significant and positive medium-grade correlation (p<0.001, R=0.45) was detected using the Spearman's rank-order correlation coefficient, between the dental age and the bone age of the patients, which shows that patients who have higher values of dental age also have higher values of bone age, as shown in Figure 6.

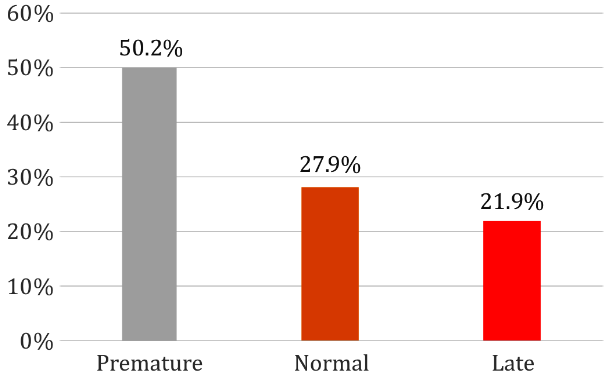

Figure 4 – *Distribution of the patients according to the dental age.*

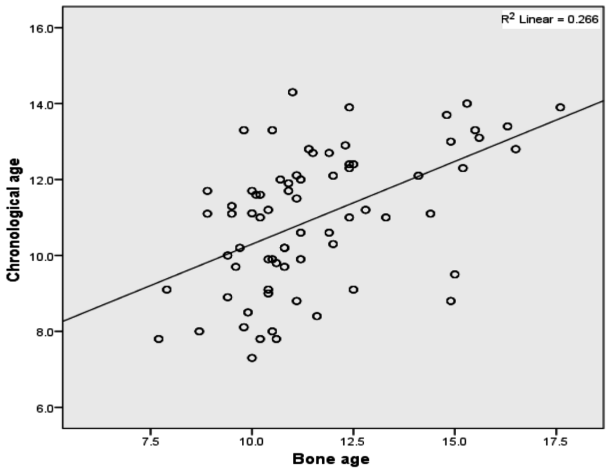

Figure 5 – *Correlation between the chronological age and the bone age of the patients.*

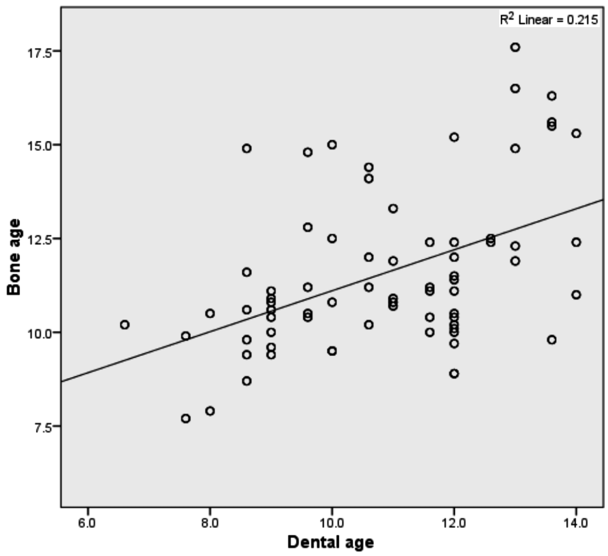

Figure 6 – *Correlation between the dental age and the bone age of the patients.*

Evaluating the bone age within dental age groups show the following results: patients with premature dental age have an average value of bone age at 12.6±2.322 years, patients with normal dental age have an average value of bone age at 10.53±1.405 years, and patients with late dental age have an average value of bone age at 10.48 ±1.033 years. Results show that the differences observed were statistically significant (p<0.001). *Post-hoc* analysis using Dunn–Bonferroni tests and also the negative medium-grade correlation established (p<0.001, R=-0.43) show that patients with premature dental age have higher values of bone age, in comparison to patients with normal (p<0.001) or late dental age (p<0.001), as shown in Tables 2 and 3, and Figure 7.

Table 2 – ***Average value of the bone age of the patients according to their dental age***

Dental age	Average ± SD [years]	*p*
Premature	12.6±2.322	<0.001* <0.001, *R*=-0.43**
Normal	10.53±1.405	
Late	10.48±1.033	

SD: Standard deviation; *Kruskal–Wallis *H*-test, **Spearman's rank-order correlation coefficient.

Table 3 – ***Post-hoc comparison of the bone age according to dental age***

Dental age*	Premature	Normal	Late
Premature	–	<0.001	<0.001
Normal	<0.001	–	1
Late	<0.001	1	–

*Dunn–Bonferroni *post-hoc* test.

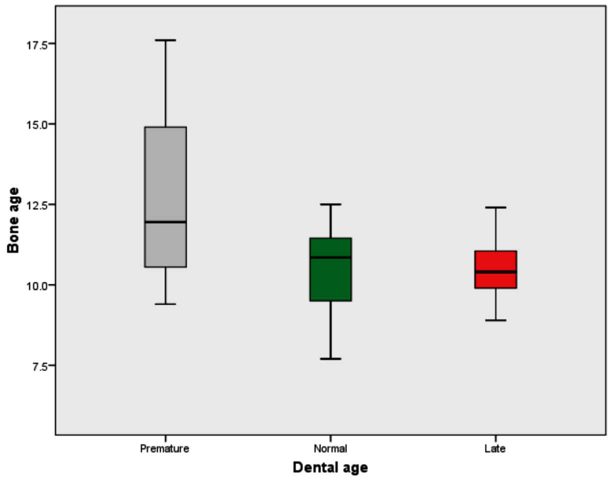

Figure 7 – ***Average value of the bone age of the patients according to their dental age.***

Finally, we decided to analyze the bone age between patients according to their gender. The average value of the bone age at females was 12.03±2.317 years and the average value of the bone age at males was 10.55±1.191 years. Results show that the differences observed were statistically significant (p<0.001), and the negative low-grade correlation (p<0.001, R=-0.281) obtained using the Spearman's rank-order correlation coefficient shows that female patients tend to have a higher average value of bone age in comparison to male patients, as shown in Table 4 and Figure 8.

Table 4 – ***Average value of the bone age of the patients according to their gender***

Gender	Average ± SD [years]	*p*
Female	12.03±2.317	<0.001* <0.001, *R*=-0.281**
Male	10.55±1.191	

SD: Standard deviation; *Mann–Whitney *U*-test; **Spearman's rank-order correlation coefficient.

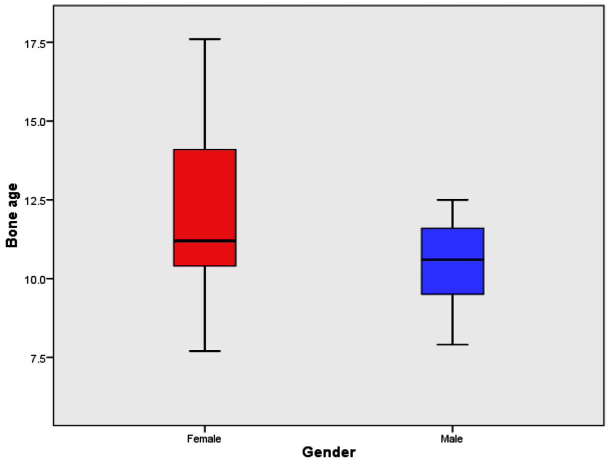

Figure 8 – ***Average value of the bone age of the patients according to their gender.***

Discussions

The comparative analysis between the dental eruption process and the chronological age is possible through an intraoral clinical examination of the teeth erupted on the dentoalveolar arches of the patient and by interpreting the stage of intraosseous development of the dental buds using panoramic radiography. Any causes that interfere with the physiological process of teeth eruption, either accelerating or delaying it, have the potential to produce age and/or order eruption discrepancies. Moreover, it was demonstrated that there are correlations between eruption discrepancies and facial typologies: leptoprosopic and euryprosopic facial types have a delayed and accelerated teeth eruption compared to the mesoprosopic facial type. For the leptoprosopic facial type, the dental eruption time is similar for the two jaws on the lateral sides of the dental arch, while the euryprosopic facial type has a more intense mandibular eruption [16].

Several methods have been developed throughout time to evaluate individual bone skeletal maturity using various biological indicators such as an increase in body height; skeletal maturation of the hand and wrist; menarche or voice changes; and CVM [13, 17–19]. The CVM method, proposed by Baccetti *et al.* [15] for the evaluation of bone development, is extremely useful for the analysis and, implicitly, diagnosis of the discrepancies in the rhythm of teeth eruption. In 1975, Lamparski [20] created the first method of assessing bone age by evaluating the morphological maturity of cervical vertebrae. He presented the standards for measuring morphological maturity of cervical vertebrae, separately for girls and boys, related to chronological age and bone age assessed considering hand-wrist radiographs [20]. Other authors, such as Hassel & Farman (1995), Mito *et al.* (2002), San Román *et al.* (2002), brought their own contribution to the method of bone age assessment from morphological changes in cervical vertebrae [21–23]. Hand-wrist radiographs are generally used to assess bone age. Many authors have investigated the possibility of accurately assessing bone age based on morphological maturity of cervical vertebrae. The authors developed comparative studies between results from bone-age evaluation using hand-wrist radiographs on the one hand and bone age assessment based on morphological maturity of cervical vertebrae using lateral cephalograms, on the other hand. These studies have demonstrated a very high correlation between bone age assessed from hand-wrist radiographs and bone age assessed from lateral cephalograms [18, 24–28]. The method based on the maturation of cervical vertebrae, besides being a fast, easy to perform analysis, has the great advantage that it is based on lateral cephalograms, which are a routine investigation before, during and after the orthodontic treatment, so that additional patient irradiation is avoided [18, 19, 27].

Baccetti *et al.* (2007) and other authors have used the method to issue a prediction on the optimal moment in which bone growth of the upper and lower jaw can be influenced, in Class II malocclusions and in Class III malocclusions [19, 28, 29]. Studies that have investigated the effectiveness of orthodontic treatment of Class II malocclusions using functional appliances type Frankel II, Bionator or Twin-block applied in CS1 and CS2 stages showed the net supplementary growth of the mandible in treated samples compared to untreated controls range from 0.5–1.6 mm to the control group, the maximum value of 1.6 mm being obtained with the use of Twin-block [29–32]. On the other hand, the efficiency of the orthodontic treatment that covered the pubertal growth period, namely CS3 and CS4 stages, revealed a median mandibular elongation from 3.9 mm to 4.3–4.7 mm using the same types of functional devices [32, 33]. At the same time, the use of Class II elastic tracts in patients treated with fixed orthodontic appliances showed an average mandible increase of 1 mm even in CS1 and CS2 stages, thus superior to treatment with Frankel, Balters or Twin-block functional devices. These fixed orthodontic appliances can only be applied in CS1 and CS2 stages to patients who do not have dental rhythm discrepancies or to those who have an advance in the development of the dentition compared to the bone development stage.

Our research shows that the dental age of the orthodontic patients is positively linked to the bone age of the patients. Also, an important percentage of the patients have a premature dental age (50.2%), these patients having a significantly higher bone age in comparison to the sample of patients with a normal dental age or with a late dental age. Female patients presented bone age discrepancies statistically significant higher *versus* male patients.

The authors of this study consider that the decision to opt for some orthodontic and orthopedic therapeutic methods with maximum efficiency on the skeletal growth of the upper and lower jaw during its growth peak is also influenced by the presence of permanent teeth on the dental arches. Thus, the rhythm disparities between the dental eruption and the bone development stage may limit the choice for some types of orthodontic appliances, the orthodontist being forced to adapt the treatment plan and the choice of the appropriate orthodontic appliances for the patient concerned, both depending on the stage of bone development and of the stage of the dentition. This study reveals the frequency of the rhythm discrepancies of the dental eruption and suggests the need to evaluate these clinical entities when planning an orthodontic treatment for a growing patient.

Conclusions

Identifying the discrepancies in the dental eruption process and an accurate differential diagnosis for them remains a challenge. The clinical therapeutic management of the eruption discrepancies is of utmost importance, giving the occlusal alteration that they produce, as well as their interferences with the orthodontic therapeutic plan in patients with malocclusions. The direct clinical examination and orthopantomography analysis allow the estimation of age-related disturbances and eruption rhythm discrepancies, comparing the two dental arches or comparing the two halves of the arches with one another. In order to assess the gaps between the dental age and the bone age, the simplified version of the CVM proved to be of great value.

Conflict of interests

The authors declare that they have no conflict of interests.

Authors' contribution

Luminiţa Ligia Vaida and Abel-Emanuel Moca equally contributed to the manuscript.

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