THE IMPORTANCE OF METHODS FOR DETERMINATION OF SQUELETAL AND DENTAL AGE IN ORTHODONTICS AND PEDIATRIC DENTISTRY – A LITERATURE REVIEW

A IMPORTÂNCIA DOS MÉTODOS DE DETERMINAÇÃO DAS IDADES ESQUELÉTICA E DENTÁRIA NA ORTODONTIA E ODONTOPEDIATRIA – UMA REVISÃO DE LITERATURA

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ABSTRACT

The stage of human development is closely related to bone or dental maturity, being essential for the choice of treatment for dentofacial changes in children and adolescents by orthodontists and pediatric dentists. There are several biological indicators to determine an individual's maturation, such as chronological age and hormonal changes, but these indicators can suffer interference. Aiming at a more accurate determination of development and growth peaks, for a better diagnosis and treatment plan, several methods have been developed to determine skeletal age and dental age, these being the assessment of carpal maturation, the morphology of the cervical vertebrae, bone fusion of the spheno-occipital synchondrosis and the median palatal suture, as well as the stages of dental calcification. The evaluation of hand and wrist radiographs is the gold standard for predicting skeletal age, and its correlation with other methods is already evident. Therefore, it is possible to use the assessment of cervical vertebrae and dental ages by Nolla and Demirjian.

Keywords: Age Determination by Skeleton. Age Determination by Teeth. Carpal Bones. Cone-Beam Computed Tomography. Radiography, Dental.

RESUMO

O estágio de desenvolvimento humano é intimamente relacionado à sua maturidade óssea ou dentária, sendo essencial para a escolha do tratamento de alterações dentofaciais em crianças e adolescentes por ortodontistas e odontopediatras. Existem diversos indicadores biológicos para determinar a maturação do indivíduo, como a idade cronológica e as alterações hormonais, porém esses indicadores podem sofrer interferências. Visando uma determinação de desenvolvimento e dos picos de crescimento mais precisa, para um melhor diagnóstico e plano de tratamento, foram desenvolvidos diversos métodos para determinar a idade esquelética e a idade dentária, sendo estes a avaliação da maturação carpal, da morfologia das vértebras cervicais, da fusão óssea da sincondrose esfeno-occipital e da sutura palatina mediana, bem como dos estágios da calcificação dentária. A avaliação das radiografias de mão e punho é o padrão ouro da predição da idade esquelética, e sua correlação com outros métodos já é evidente. Sendo assim, é possível utilizar a avaliação das vértebras cervicais e das idades dentárias de Nolla e Demirjian.

Palavras-chave: Determinação da Idade pelo Esqueleto. Determinação da Idade pelos Dentes. Ossos do Carpo. Tomografia Computadorizada de Feixe Cônico. Radiografia Dentária.

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INTRODUCTION

Chronological age is not the most reliable indicator for predicting human development, as it can be influenced by genetic, racial, environmental, nutritional, hormonal, and sexual factors, often not coinciding with physiological age, which is extremely important for diagnosis, treatment planning and prognosis, mainly in Pediatric Dentistry and Orthodontics. There are several biological ages, for example: bone age, morphological age, menarche age and dental age, which have been proposed to determine physiological age (1).

In Dentistry, determining physiological maturation is essential for evaluating the need and ideal time for orthodontic treatment, as each person has a biological clock, which regulates the time needed to reach the adult state, with maturity being the product of a process (two). During this maturation process, development stages occur at different speeds that follow the general growth trend of the body, occurring, more markedly, in the first decades of life, with decreasing speed – except for two accelerated phases, called growth peaks. The first period occurs during childhood, usually 6 to 8 years of age, and is called a childhood growth spurt. The second peak occurs during puberty, which is more pronounced and evident, the so-called pubertal growth spurt (PCS), which is most useful for the orthopedic treatment of bone dysplasias (3).

Through the precise determination of the PCS, it is possible to evaluate the peak growth velocity of each person, whether imminent, present, or complete (4). This point is fundamental for determining orthodontic treatments related to malocclusions caused by craniofacial skeletal changes, as it is possible to obtain the best results in a relatively shorter period, due to the direct relationship between the growth peak during puberty and the maxillo-mandibular dimensions. (5). Furthermore, it assists in the diagnosis, planning and early treatment of anomalies, as the prognosis of orthodontic therapy is directly related to the individual's growth and physiological maturation (6).

Given this context, this study aims to review the literature on the mentioned methods, in order to contribute as another means of information and resource in the diagnosis and planning of clinical cases in Pediatric Dentistry and Orthodontics. Herein, it serves as a tool to facilitate routine guidance for patients.

LITERATURE REVIEW

The scientific literature was reviewed in the electronic databases PubMed and Google Scholar in September 2023. The combinations of terms included were: "Age Determination by Skeleton" or "Age Determination by Teeth". Articles that used any of the skeletal age prediction methods were included - suggested by Greulich and Pyle (7), Lamparski (8), Hassel and Farman (9), Baccetti (10), Bassed (11) and Angelieri (12) – or dental – suggested by Nolla (13) and Demirjian (14). There was no date restriction. Review articles, letters, editorials, and articles with forensic and/or criminal objectives were excluded. Additionally, only articles in Portuguese and English were selected, and those that did not present human samples, or that the evaluation had been carried out on syndromic patients or those with a disease were excluded.

After searching for articles in the databases, the title and summary were read, and the selection criteria were applied. Then, the chosen articles were read in full, excluding those that were not found in their complete version or did not present the proposed theme.

Skeletal age analysis

Although growth spurts are generally present in every healthy population, these phenomena do not occur at the same chronological age for everyone, because they can be influenced by several factors, such as: genetic, socioeconomic, nutritional, among others. Thus, one of the most used ways to observe the growth and physiological maturation of individuals is the analysis of skeletal age (3). According to Greulich and Pyle, the skeleton provides a more useful measure of the individual's level of general maturity and can be used from birth until complete bone development (7).

Various parts of the human body can be used to determine skeletal growth through bone morphology and size. One of the most used and researched methods is the evaluation of hand and wrist radiographs, due to the ease of the radiographic technique and the reduced amount of radiation to which the individual is exposed, but, mainly, because of a large number of ossifications in a relatively small area (7,15).

Carpal radiographs have been used to analyze bone development since 1896, and since then, several assessment methods of this type have been created. Greulich and Pyle created an atlas using the sequence of the ossification centers of bone maturation of the hand and wrist. To carry this study out, a sample of 100 American children was used, from birth to 18 years old for females, and up to 19 years old for males. The authors created a pattern by dividing them into certain chronological ages, correlating with the greatest possible coincidence of mineralization centers, anatomical shape, dimensions, and developmental stages of the epiphyses, being divided by male and female sex. The method therefore consists of comparing the carpal radiograph of the individual to be analyzed with the standard defined in the Greulich and Pyle Atlas (7).

To verify the clinical applicability of the Greulich and Pyle Atlas, Koch *et al*. analyzed 225 Turkish boys between 7 and 17 years of age. The authors found that skeletal ages were below the average chronological age in the period from 7 to 13 years of age, and advanced in the period from 14 to 17 years of age. Based on these findings, the authors concluded that Turkish boys have different bone maturation times compared to those studied by the Greulich and Pyle Atlas, which should be applied to this population with a correction factor (17). Other authors have also evaluated Greulich and Pyle's method in different ways. There are those who concluded that the Sauvegrain method is more accurate when compared to the Greulich and Pyle method, however, this finding appears in a study that presents a methodological deficiency regarding the comparison, which is carried out in a single moment (18). The Sauvegrain method uses radiographs in lateral and anteroposterior views of the elbow that evaluate the degree of maturation of some bones and correlate with the estimated bone age. Another manuscript, which reported research with a Taiwanese population, demonstrated inaccuracy in the Greulich and Pyle method (19).

On the other hand, another study also with a Taiwanese population showed that with adjustments to adapt to the studied population and considering that the Greulich and Pyle method takes less time and covers a wider age range, which was chosen as the most useful method clinic (20). From this perspective, there is a report of no significant difference between bone age and chronological age when using the Greulich and Pyle method (21). There is also a study that concluded that the Greulich and Pyle method appeared to be reasonably reproducible for assessing skeletal age (22). Besides, Koc *et al*. showed that the use of automated tools for estimating bone age with the Greulich and Pyle method can reduce interobserver variability and increase prediction accuracy (23). Booz *et al*. stated that artificial intelligence could improve the efficiency of clinical routine without compromising accuracy (24).

Even though the evaluation of carpal radiographs may be a widely accepted method, there is a tendency to use other methods of analyzing skeletal maturation, thus seeking to provide alternatives for professionals and, mainly, to reduce the ionizing radiation to which individuals are exposed because, despite the low dose, it constitutes an additional exposure (3). Hence, there are methods in which the cervical vertebrae are used to analyze skeletal age, since the lateral cephalometric x-ray is a determination exam in the diagnosis and orthodontic planning protocol. Currently, there is also a growing demand for cone beam computed tomography (CBCT), which provides three-dimensional analysis, especially in cases of impacted teeth, skeletal dysplasias and severe asymmetries, enabling a more accurate diagnosis and treatment plan. This fact stimulated the search for skeletal assessment methods visible in these exams, which could thus replace hand and wrist radiography (25).

Analysis of cervical vertebrae is associated with changes in size and shape during vertebral growth during adolescence. According to the study by García-Fernandez *et al*., the analysis of cervical vertebrae to determine the state of bone maturation began in the 1970s, when Lamparski observed the morphological changes in these structures, classifying them into six stages and establishing a subsequent comparison with the skeletal changes seen in the hand and wrist region, concluding that the cervical vertebrae are also effective in predicting bone age (8,26). In 1995, Hassel and Farman improved the method studied by Lamparski with the analysis of morphological changes occurring only in the second to fourth cervical vertebrae (C2, C3 and C4), classifying them into six cervical vertebra maturity indices (CVMI) and determining the remaining PCS (9).

Several other authors also found a high correlation between the maturation of cervical vertebrae and skeletal maturation, which is considered in the literature as a reliable method with easy clinical applicability (27-32), but there is still a certain reluctance among dental surgeons to replace the use of hand and wrist x-rays, despite the cost and additional radiation for the patient (33).

Considering the analysis of the maturation of cervical vertebrae, the method developed by Baccetti *et al*. stands out, who presented a new version of the method (10). They carried out an annual measurement of the mandibular dimension of 214 individuals and analyzed the inferior concavity of the C2, C3 and C4 cervical vertebrae (Chart 1). The assessment of concavities was divided into six stages. In stage 3, all presented concavity at the lower edge. The authors found that the appearance of the concavity in C3, which occurs between stages 2 and 3, can be correlated to the pre-peak of mandibular growth (34).

CHART 1 – DESCRIPTIVE CHART OF THE MATURATION STAGES OF THE C2, C3 AND C4 CERVICAL VERTEBRAE ACCORDING TO BACCETTI *ET AL.*, 2002; BACCETTI *ET AL.*, 2005 (22,23).

Stage CS1	The lower edges of C2, C3 and C4 are flat. The bodies of C3 and C4 have trapezoidal morphology. The peak of the mandibular growth spurt will occur, on average, two years after this stage.
Stage CS2	The lower edge of C2 has a concavity. The bodies of C3 and C4 have trapezoidal morphology. The peak of the mandibular growth spurt will occur, on average, one year after this stage.
Stage CS3	The lower edges of C2 and C3 are concavity. The bodies of C3 and C4 can have trapezoidal or horizontal rectangular morphology. The peak of the mandibular growth spurt will occur during the year after this stage.
Stage CS4	The lower edges of C2, C3 and C4 are concavity. The bodies of C3 and C4 have horizontal rectangular morphology. The peak of the mandibular growth spurt occurs one to two years before this stage.
Stage CS5	The lower edges of C2, C3 and C4 are concavity. At least one of the bodies of C3 and C4 has a quadrangular morphology. If it is not square, the body of the other vertebra remains with a horizontal rectangular morphology. The peak of the mandibular growth spurt stops at least one year before this stage.
Stage CS6	The lower edges of C2, C3 and C4 are concavity. At least one of the bodies of C3 and C4 has a vertical rectangular morphology. If it is not vertically rectangular, the body of the other vertebra is quadrangular. The peak of the mandibular growth spurt ends at least two years before this stage.

The methods for assessing skeletal maturation have a strong correlation with each other (35). There are studies that have correlated chronological age with skeletal age. One of them showed that there was a high correlation in Yemeni children (36). In the study by Magat and Ozcan, all correlations between dental and skeletal stages were statistically significant (37), and there are already proposals for artificial intelligence models to evaluate CVMI in cephalometric radiographs (38).

Another way of assessing skeletal age that can be used by the dentist is the observation of late fusion of the spheno-occipital synchondrosis (SOS), which is one of the most significant growth centers at the base of the skull, with a fundamental role in the development of the maxillo-mandibular complex (1). Scheuer and Black stated that the SOS shutdown almost certainly occurs during adolescence. They also added that the fusion times of intra-occipital and SOS are related to significant maturational events (39). Bassed *et al.* proposed a method for evaluating SOS in which five stages of ossification are defined, which begin with SOS without fusion, passing through the successor stages, which present the progression of ossification, until the complete obliteration of SOS, as shown in Chart 2 (11).

CHART 2 – DESCRIPTIVE CHART OF THE MATURATION STAGES OF SPHENO-OCCIPITAL SYNCHONDROSIS (SOS) ACCORDING TO BASSED *ET AL.*, 2010 (26).

Stage 1	SOS is completely open and unmerged.
Stage 2	The top edge of the SOS is merged.
Stage 3	Half of the length of the SOS is merged.
Stage 4	SOS is almost all merged, but one site is still visible.
Stage 5	The site is completely obliterated, presenting the appearance of normal bone.

Delayed fusion of the midpalatal suture can also be used to determine the patient's stage of bone maturation. The classification is made through analysis of the CBCT examination or occlusal radiography, as both allow visualization of the general anteroposterior characteristics of the suture, without overlapping other anatomical structures. This method can provide reliable parameters for planning therapeutic approaches (40).

In 2013, Angelieri *et al.* (12) developed a study based on the morphology of the median palatal suture under observation during growth. For this purpose, CBCT images of 140 individuals were examined to define the radiographic stages of maturation of the midpalatal suture, establishing a scale of five stages of maturation of the midpalatal suture, which were identified and defined as shown in Chart 3.

CHART 3 – DESCRIPTIVE CHART OF THE STAGES OF OSSIFICATION OF THE MEDIAN PALATAL SUTURE ACCORDING TO ANGELIERI ET AL., 2013 (28).

Stage A	The midpalatal suture is almost a straight high-density line with no interdigitation.
Stage B	The midpalatal suture takes on an irregular shape, and a high-density stepped line appears.
Stage C	The median palatal suture appears as two parallel, stepped, high-density lines that are joined to each other, but separated by small, low-density spaces in the maxillary and palatine bones (between the incisive foramen and the palato-maxillary and posterior suture). the palato-maxillary suture).
Stage D	The suture may be arranged in a straight or irregular pattern.
Stage E	Fusion of the median palatal suture occurs in the palatal bone, with progressive maturation from posterior to anterior.

Dental age x growth prediction

Because of the need for more practical methodologies for predicting physiological maturation, dental age has also been intensely studied as it is a data easy to obtain and evaluate during routine dental treatment (41). Furthermore, dental mineralization follows a relatively constant developmental sequence and is more reproducible when checking chronological age (6). Correlations between the stages of dental calcification and skeletal maturity have been described, which allows, in a more practical way, the identification of the individual's stage of physiological maturation based on panoramic radiography, an exam commonly requested by professionals (41).

The development of carpal bones and teeth is correlated, according to Marshall, and it was highlighted that both can be used to represent physiological development, as they occur simultaneously (42). Chertkow and Fatti investigated the relationship between the mineralization stages of various teeth and hand and wrist ossification in a sample of 140 individuals. They concluded that the relationship between the lower second permanent molar and the calcification of the sesamoid adductor bone was low, with females developing earlier compared to males. They also noticed that men's dental development tends to be faster than bone, when compared to women's (4).

Dental mineralization has been the most appropriate method for estimating chronological age, according to Ferreira Júnior *et al* (43). The authors stated that women tend to be precocious. In the study, they found that homologous teeth, in the same arch, undergo the mineralization process together and the differences between them are statistically insignificant for all individuals. They also observed that at 6 years of age, girls show more accelerated mineralization than boys for the lower first and second molars (43).

The Nolla method is world-renowned and was developed with the purpose of studying the development of permanent teeth. To this purpose, annual panoramic radiographs were taken of 50 children between 55.3 and 201.8 months of age and analyzed, with a schematic drawing created dividing dental calcification into 10 phases, from the beginning of crown formation until apical closure. The application of this method is based on assigning a degree of mineralization to each of the permanent teeth in a quadrant, which corresponds to a development stage value. The sum of the values for each tooth is compared with the standard values that appear in the maturation tables and correspond to the average chronological ages, separated for each sex. In conclusion, tooth development is similar, and no differences were observed between females and males (13) (Chart 4).

CHART 4 – DESCRIPTIVE CHART OF THE STAGES OF DENTAL CALCIFICATION ACCORDING TO NOLLA, 1960 (32).

Stage 0	Absence of dental crypt.
Stage 1	Presence of a dental crypt.
Stage 2	Beginning of tooth calcification (crown).
Stage 3	Formation of one third of the dental crown.
Stage 4	Formation of two thirds of the dental crown.
Stage 5	Almost complete formation of the dental crown.
Stage 6	Complete formation of the dental crown.
Stage 7	Formation of one third of the tooth root.
Stage 8	Formation of two thirds of the tooth root.
Stage 9	Almost complete root formation, but with its apex open.
Stage 10	Root apex closure.

Dental development is one of the most real indicators of chronological age, according to Bolaños *et al*., who researched the best tooth to estimate chronological age, using the Nolla method. The sample used was 374 panoramic radiographs, 195 of which were male and 179 females. The authors concluded that for females under 10 years of age the best predilections for chronological age were the upper central incisor, the first and second lower molar, while for males, they were teeth the upper central incisor, the lower canine and the lower first molar (44).

In 1999, a study by Rossi *et al*. evaluated the correlation between the stages of root mineralization of lower second permanent molars and calcification of the first finger. They used a sample of 71 female children, aged 8 to 13 years, and took intraoral x-rays and x-rays of the thumb on the left side on the same day. From the results, the authors found that most children were in Nolla stages 6 and 7 did not yet have the sesamoid bone. They highlighted, thus, that bone maturation is one of the most useful tools for analyzing development and that dental age can be determined through erupted teeth or by analyzing tooth formation on intraoral radiographs (45).

Dental age can also be analyzed by applying the Demirjian method, based on the mineralization of the seven left mandibular teeth. This method is based on a dental age scoring system that uses objective criteria and relative values rather than absolute lengths. Shortened or lengthened projections of developing teeth do not affect the reliability of the assessment. Identified by letters from A to H, the stages comprise the process of tooth mineralization from the crown to the apical closure. The application is based on assigning a value to each tooth, according to its degree of mineralization and according to the sex of the individual analyzed. The sum of these values is on a scale from 0 to 100, in which the values will be compared to pre-established values, resulting in correspondence to the individual's chronological age (14) (Chart 5).

Studies that compared dental age prediction methods were also carried out and a strong correlation was found between chronological and dental age (46). One study chose Nolla's method as the most reliable, followed by Willems and, the least reliable, Demirjian (47). Although the Demirjian and Willems methods showed a high correlation, the second was considered the most appropriate in another study (48). For Barati *et al*., the Willems method is also preferred (49). Demirjian's method has been questioned regarding the degree of prediction when the sample is treated as homogeneous and segmented by age and sex groups (50), also regarding the variability of ethnic groups (51). For children in southern Saudi Arabia, for example, Nolla's method was effective (52). Contrastingly, Marrero-Ramos *et al*. showed that Demirjian's method is reliable for estimating a person's oldest age (18 years) (53), and efficient for predicting skeletal maturity when comparing dental calcifications in Korean children (54). There is a suggestion that the Demirjian method may be a valuable tool for estimating age through the mineralization of third molars (55). By estimating dental age using the Demirjian method, it is possible to predict the degree of maturity, providing the choice of the ideal moment to start orthodontic treatment (56). Finally, research showed that the automated method outperformed the classical approaches tested (Demirjian and Willems methods) (57).

CHART 5 – DESCRIPTIVE CHART OF THE STAGES OF DENTAL CALCIFICATION ACCORDING TO DEMIRJIAN *ET AL*., 1973 (14).

Stage A	Beginning of calcification in the upper portion of the crypt, in the shape of a cone or inverted cones, without fusion between the points of calcification.
Stage B	Fusion of calcification points, formation of cusps and delimitation of the occlusal surface.
Stage C	Complete formation of occlusal enamel, beginning of cervical extension, deposition of dentin in the upper portion and beginning of the contour of the pulp chamber.
Stage D	Crown almost complete before the cementoenamel junction, roof of the pulp chamber well defined.
Stage E	More defined walls of the pulp chamber, root size smaller than the height of the crown for posterior teeth, marked presence of pulp horns and beginning of root bi- or trifurcation.
Stage F	Pulp chamber walls forming an isosceles triangle, root size similar to or slightly larger than crown height; In the furcation region of the posterior teeth, the calcification has a semilunar shape, and the canals are wide, with walls ending in a bevel.
Stage G	Canal walls parallel and apex partially open.
Stage H	Closed apex and uniform periodontal space around the root and apex.

CONCLUSION

Based on this review, the controversy surrounding methods for predicting skeletal and dental ages is evident, sometimes exposing some methodological deficiencies and the heterogeneity of results when evaluating different ethnic groups. However, the evaluation of hand and wrist radiographs is the most studied and most referenced, and its correlation with other methods has already been established. Hence, it is possible to use the assessment of the cervical vertebrae and dental ages of Nolla and Demirjian. The importance of such methods is unquestionable, whether just because they predict age, or because they make it possible to correlate two assessments, but mainly from the perspective of applying the different methods of assessing skeletal and dental age as diagnostic and planning resources in guiding clinical cases in Pediatric Dentistry and Orthodontics.

The authors declare no conflicts of interest.

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