Estimation of child’s biological age based on tooth development

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Abstract: Dental development is relatively independent from other systems maturation. Recent studies have reported changes in the timing of tooth development for contemporary children comparing to children that lived more than 30 years ago (secular trend). Detectable variations in the tempo of tooth mineralization and duration of tooth maturation between children from different geographical regions were reported. Dental age is important not only for dental specialists, but also for pediatricians (in the evaluation of growth and development of healthy children, in pediatric endocrinology, in children with different diseases or syndromes) and forensic doctors (in order to estimate the age or to identify the child). The aim of our study was to investigate the regional characteristics of dental maturation in actual Romanian children. We conducted a cross-sectional study on a final sample of 441 radiographs of patients aged between 5.5 and 14.5 years (218 girls and 223 boys). The dental panoramic radiographs were scored by two examiners and intra- and inter-examiner calibration was made. We used a dedicated software for easy scoring, automatic dental age determination and as a database. On average, the Romanian girls showed an overestimation of 0.36 years, meaning 132 days, p=0.129, α = 0.05 and boys an underestimation of 0.04 years, meaning 15 days, p = 0.852, α = 0.05. New tables were developed in order to convert dental maturity calculated according to Demirjian method into dental age of contemporary Romanian children.

Key Words: stages of permanent tooth development, dental age, diagnostic tool, Romanian children sample, digital imaging technologies

The physiological age of a person is determined by the degree of maturation of the different tissue systems [1]. Physiological age can be used to define a child’s progress towards completeness of development or maturity. Within a tissue system, the sequence of one or more irreversible events defines maturation. Dental Age is usually based on the maturation of the teeth [2]. This is observed when we look on a child’s panoramic radiograph (Figure 1, 2).

Children with the same chronological age may show differences in the developmental stages of different biological systems. Several indices have been developed to determine the developmental stage of a child for a certain biological system, namely indices for sexual maturity, somatic maturity, skeletal age, and dental age [3].

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Physical growth often deviates to the chronological age, but correlates well with skeletal age that represents relative stage of bone maturation. Among all the growth indicators, dental age has the weakest correlation with general somatic development. There is a good correlation between dental age and chronological age in general [4].

The correlations between dental, skeletal and chronological age are relevant in orthodontics, pediatric dentistry, pediatric and forensic medicine. For both dental specialists these correlations allow an overall summary of dental development and can be used as a basis for further therapeutic decisions.

Such knowledge as dental and skeletal age can be useful in taking the decision about extracting primary teeth and to decide on timing of the orthodontic treatment. In patients with delayed dental maturity, orthodontic treatment may be started at a later stage, thus leading to shorter treatment duration and more stable results [5]. In case of over-retained deciduous teeth the method facilitates determination of the right time for starting treatment.

The degree of calcification and the stages of the teeth give the clinician information about abnormal sequences (e.g. eruption of second molar ahead of second premolar in the mandible arch) so that the preventive measures can be taken in time [6]. Dental maturation has been studied in cases with different malocclusions and different facial types (as in extreme vertical facial type) [7]. The relationship between dental age and skeletal age (cervical vertebrae maturity) has been also investigated [8]. Pediatricians are interested to know if the dental and skeletal maturity of a child with certain disease is delayed or advanced [9, 10-11].

Skeletal and dental age is important in each growth and development evaluation of a child and in pediatric endocrinology. Some surveys have been conducted in order to evaluate skeletal, craniofacial growth and dental maturation on children with short stature of prenatal origin [12], boys with constitutionally delayed puberty [10], in children with juvenile rheumatoid arthritis [11], in children with fetal alcohol syndrome [13] and other diseases. The correlation between dental and chronological age is also useful in forensic dentistry to estimate the age or to identify the child [9, 14]. There are also studies that highlight the value of different ante mortem dental radiographs in establishing the identity of humans [15, 16].

Dental age can be determined according to the simplest and oldest technique: clinical emergence of the teeth, which is erroneously called eruption because it represents only one stage in the continuous process of dental eruption. This method can only be used during relatively short periods because between the ages of 2.5-6, 8-10 and 13-18 years no teeth will emerge [3]. Visible emergence usually occurs when root formation is about three quarters completed, but quite large departures from this rule have been observed [1]. Emergence may be influenced by local factors: ankylosis, early or delayed extraction of the deciduous tooth, impaction and crowding of the permanent teeth [1].

When Schour et al. discovered in 1941 that tooth mineralization is a constant, ongoing process, they established a scheme of tooth mineralization and an other method was developed [6, 17].

Techniques for chronological age estimation in children based on dental maturation may be divided into those using the atlas approach and those using scoring systems whereas in adults there are the morphological and radiological techniques [18].

Many authors have published techniques in order to assess dental maturity by tooth formation: Demirjian, Goldstein, Tanner, Glombitza, Nolla, Prahl Andersen and van der Linden [1, 19-21].

The atlas approach, developed by different authors uses radiographs where morphologically different stages of tooth mineralization are compared with atlas tables [17, 20-26]. Authors as Schour and Massler, Moorrees et al, Andreson et al, Nolla and Nicodemo developed well known and applied atlas approach techniques [27, 28].

The techniques that are using the scoring system tried to simplify chronological age estimation and restricted the number of teeth studied to 7 (developed by Demirjian, Goldstein, Tanner in 1973) [1] or 4 [9, 29]. The investigation of Demirjian in 1973 resulted in the creation of a dental maturity scaling system that has been found the most easy to use, the most accurate and that is confirmed by the use in so many studies in the whole world. We also used it in our study (Figure 1, 2).
The method developed in Zurich, taking in account usually one tooth is not the most accurate, but provides a quick and easy age assessment (Figure 1, 2). Between 3 and 12 years, we can best estimate dental age considering the stages of dental development and mineralization of first lower premolar (the beginning of mineralization at about 2 years and a half, crown development that lasts approximately 4 years and root development that last about 5-6 years) (Figure 3). The estimated age could be proved, applying similar methods and taking in consideration other permanent teeth [30, 31].

The mineralization of enamel (visible on radiograph) starts at birth for the upper and lower first molars, at 6 months for the first upper and lower central incisors and lower lateral incisors, at 12 months for the upper and lower canines, at 18 months for upper lateral incisors, at 2 and a half years for the upper and lower first premolars, at 3 years for upper and lower second premolars, at 3 years and a half for upper and lower second molars and at 10 years for the third molars. The normal variation is approximately 6 months (more or less) [31]. At intraoral emergence stage the root has developed more than two thirds of its final length. Insufficient root development is characteristic of premature eruption (e. g. root has one third of its final length) [32].
Figure 3. Dental age assessment considering the development stages of one tooth: the lower first premolar (3.4). The description of the stages by Hubertus van Waes and Paul Stockli [30, 31] (left), the stages exemplified on our radiographs (center) and the results of our study regarding the stages of development for the same tooth for each age group (right).

Today, children are maturing earlier than they did at the beginning of this century and moreover, they are growing faster than their grandparents and great grandparents. Various studies have shown that an analogous correlation between skeletal and dental maturity, as is found in the relationships between growth, skeletal, sexual and somatic maturation, does not exist. Dental development is relatively independent from other maturation phenomena. Studies have found, however, acceleration in tooth eruption at contemporary children [33].

Many authors have reported different standards of dental maturation, using different methods, assessed at different populations: Indian [28, 34-36], Chinese (Chengdu) [37], Senegalese [38], Australian [2], South African [27], Saudi [39], Pakistani [5], Brazilian [25, 26] and also Europeans. Among the last group are: German from south-western Germany [6], Finnish [40, 41], Norwegian [42], Swedish [43], British [2, 44, 45], Hungarian from south-western Hungary [46], Dutch [3], Danish [47], Italian [9], Turkish [48], Polish from Central Poland [49], French from South France [50].

After determining their own standards many of these studies compare the results with data of populations other than French-Canadian that have determined the dental age standards before. Sexual differences in dental development were always studied for each age group and prediction of emergence were sometimes made [1, 51].

Purpose

As the entire growth and development is accelerated it is possible that we have a faster dental development as well.

Our clinical day by day observations proved that there are differences between chronological age and dental age calculated according to Demirjian standards, at Romanian children.

The objectives of this study were: dental maturity assessment from orthopantomograms using Demirjian method and creation of a database for Romanian children; to evaluate the applicability of dental age assessment tables developed for French-Canadian children for our population; to develop new standards for Romanian children; to compare the results with those of other European countries; to assess the sexual differences in dental development; to develop tables with the stages of development of lower permanent teeth at different ages; to compare dental age determination on digital against conventional radiographs; to investigate when the first premolar method can be used in the clinical practice. Some of these were the objectives of our other partial studies [52-54].
Materials and methods

We conducted a cross-sectional retrospective study on a sample of 467 panoramic radiographs of patients aged 3.5 to 16 years, from which 230 females and 237 males. The radiographs were collected from five different private dental offices and from the Clinic of Paedodontics-Orthodontics from Timisoara.

The inclusion criteria were: children of Romanian origin (Romanian parents); pretreatment radiographs of all the paedodontic and orthodontic patients (it is not possible to conduct a radiographic survey on perfect dentitions from bioethical reasons, although the results would be the most accurate for determining normal standards); healthy children; free from any disorder affecting growth; good radiographic quality; the presence of all seven left or right mandibular permanent teeth (erupted or not). The exclusion criteria were: general health problems; endocrine or nutritional disorder because this may affect child’s development; genetic problems; craniofacial syndromes; extractions, agenesis and pathological processes in the apical bone of the same permanent teeth on both sides of the mandible; the same missing teeth on both mandibular sides, except third molars; prior orthodontic treatment history.

At the end, a number of 26 assessed radiographs (12 of female and 14 of male subjects) were again excluded, because the number was insufficient to represent the following age groups: 3.5-4.4, 4.5-5.4 and 14.5-15.4, 15.5-16.

The final sample which we used in our survey included 441 radiographs of patients aged between 5.5 and 14.5 years (218 girls and 223 boys), (Figure 4). We divided the sample in groups, considering an age interval of one year (Figure 5).

The radiographs were rated by two examiners, which trained together. Intraexaminer disagreement occurred in 12% of the cases, for the first examiner and 4% of the cases for the second examiner and interexaminer disagreement occurred in 9.2% of the cases. Such intraexaminer and interexaminer differences have been considered reasonable in other studies [1].

Each examiner rated each of the seven left mandibular teeth. The third molar was excluded. In all the cases in which we had anodontia, extractions of permanent teeth or premature loss of primary teeth on this side, we rated the corresponding teeth on the right side.

Tooth formation is divided into eight stages (A- mineralization of single occlusal points without fusion of the calcifications, B- fusion of the calcifications - occlusal outline recognizable, C- enamel development of the crown completed, beginning dentine deposition, D- crown development completed up to the enamel-cement-verge, E- root length shorter than height of the crown, F- root length greater or equal to height of the crown, G- root development completed, Foramen apicale still open, H- Foramen apicale closed) on which adds the 0-stage (tooth germ without any signs of calcification) (Figure 6). Each tooth included has an individual development stage and then a corresponding score, according to normal standards, which are gender dependent (Figure 1, 2).

The parameters birth date, date of radiograph were used to calculate chronological age; gender and developmental stages of the teeth and the score tables from Demirjian et al. were used to calculate the scores for each tooth (Figure 5). The values are added and the sum is transformed to dental age.
The standard values for the dental age assessment are given. This methods and clinical norms developed by Demirjian et al. are recommended by Thomas Rakosi [1, 32] and are used by OnyxCeph3TM software, developed by the firma Image Instruments GmbH, Germany [55].

All the determined data where included in a large database in order to be analyzed with statistical methods in the Department of Medical Informatics and Biostatistics from Timisoara. The program used was SPSS v. 17.

Results

A paired t-test was used to assess the difference between chronological age (the true age) and dental age (the assessed age), according to the method of Demirjian (Figure 7, 8). The differences were insignificant considering the whole sample (-0.36 years, meaning 132 days, p=0.129, α = 0.05 for girls and 0.04 years, meaning 15 days, p = 0.852, α = 0.05 for boys). They were significant in the following age groups: 5.5 to 6.4 (-0.82y, p <0.001), 11.5 to 12.4 (-0.51y, p = 0.026), 12.5 - 13.4 (-0.82y, p = 0.013) and 13.5 to 14.4 (-0.56y, p = 0.016) for girls and 13.5 to 14.4 (-0.74y, p = 0.028) for boys. In girls, dental maturation was ahead of chronological age for all age groups, whereas in boys the chronological age is ahead of dental maturation in most age groups, except the following age groups: 5.5-6.4, 6.5-7.4 and 13.5-14.4.

As dental maturity assessed using Demirjian method and chronological age showed a curvilinear relation on a scatter plot (logistic regression), therefore, transformation $\ln\{y/100 - y\}$ was performed to make the relationship linear, where “y” is the dental maturity and “x” is the chronological age (significant, direct and strong linear correlation-Pearson coefficient r=0.813, p<0.001) (Figure 9).
The average values of score sums for girls and boys, for each age group were determined (Figure 10). We also determined the median development stage, for each tooth by age and sex. For 3.1 (the lower left central incisor) the apex was closed (stage H) in the age interval 7.5-8.4 in females and 8.5-9.4 in males. For 3.2 (the lower left lateral incisor) the apex was closed (stage H) in the age interval 8.5-9.4 for females and 9.5-10.4 for males. For 3.3 (the lower left canine) the apex was closed in the age interval 12.5-13.4 for females and 13.5-14.4 for males. For 3.4 (the lower left first premolar) the apex was closed in the age interval 12.5-13.4 for females and 13.5-14.4 for males. For 3.5 (the lower left second premolar) the apex was closed in the age interval 9.5-10.4 for females and 10.5-11.4 for males. For 3.6 (the first left lower molar) the apex was closed in the age interval 14.5-15.4 for both females and males (Figure 11).

**Discussions and conclusions**

In our study, girls indicated advanced dental development in all age groups and reached dental maturation earlier than boys, according to earlier maturation of other parameters of growth and development: sexual maturation, weight, height and skeletal development.

The dental age was advanced to chronological age, for all age groups, in girls. The differences were significant at the beginning of tooth eruption, in small girls, aged between 5.5 and 6.4, and at the end of
tooth eruption, between 11.5 and 14.4, around the peripuberal growth spurt. In boys, the dental age was little advanced between 5.5 and 7.4 years and significant advanced between 13.5 and 14.4 years, around their growth spurt. Between 7.5 and 12.4 dental age was little delayed in boys.

We can apply on our children the Demirjian standards prescribed for French-Canadian children for most age groups. We have to use the developed tables for those age groups, where the differences between dental and chronological age were significant, which results from the paired t-test applied.

We compared the mean differences between chronological and dental age for boys and girls with the mean differences of other populations. The Romanian population was compared to the following populations: Indian, Belgaum (-0.04y for girls and -0.14y for boys); Pakistani (-0.83y for girls and -0.59y for boys); Senegalese (-0.48y for girls and -0.89y for boys); Indian, South (-2.82y for girls and -3.04y for boys); Turkish (dental age advanced between 0.50y and 1.44y for girls and between 0.36 and 1.44 for boys); Dutch (-0.6y for girls and -0.4y for boys); Poland (dental age accelerated in boys and girls at different ages); Chinese, Chengdu (in all, girls were more advanced 0.45y than boys); Hungarian (boys and girls were approximately 1 year ahead to French-Canadian children); Finnish (dental age advanced between 0.35y and 0.9y for girls and between 0.45y and 0.7y for boys); Norwegian (dental age ahead 0.3y for girls and 0.2y for boys); Swedish(dental age advanced between 0.5y and 1.8y for girls and between 0.4y and 1.8y for boys);

The dental apex is closed approximately one year latter for boys, then girls for all the mandibular teeth examined, except the second lower molar for which the apex closes at the same age (between 14.5 and 15.4 years), possible because boys have also reached their growth spurt. The lower canine and both premolars close their apex almost at the same time.

Digital radiographs have a lot of advantages: the irradiation is reduced with 80% when comparing with the classic ones, the clarity of the image is much improved (the clarity is very important when we want to distinguish between two proximal stages, for example when we want to decide if the apex is closed-stage H or the apex is not closed-G) and less artifacts (Fig 1, 2). These images can be analyzed with dedicated software, as proposed in the user manual for OnyxCeph3TM software [55]. Except the conversion tables, that we had to update for our population with OnyxCeph3TM we can save, review and control the stages previously given each time without the need of any other elements, except our computer.

The frequency of radiographs recommended is lower at young ages (3.5-5.4 years age intervals), according to low treatment need and radiation management bioethical reasons and also in adolescents (between 14.5 and 16 years). We would need to add more radiographs to the existent in order to extend our study for the groups mentioned before.

We decided to make all our investigations on contemporary healthy children in order to develop standard values for actual Romanian population. There is a demand of further studies, done on children with different diseases or syndromes. Other studies would be needed in order to investigate the secular trend on our population.

We try to characterize each age with standards as closed to reality as possible, but when we have to make a diagnostic we have to use the recommended standards keeping in mind that each child is unique regarding his growth and development.

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References