

Brief communication (Original)

Evaluation of dental and skeletal maturity using digital panoramic radiographs and digital cephalograms

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Background: Assessing the maturational status and pubertal growth spurt of a patient has considerable influence on diagnosis, treatment planning, and the outcome of orthodontic treatment.

Objectives: To assess the usefulness of panoramic radiographs as a tool to estimate the growth and to ascertain the importance of tooth calcification stages as an indicator of maturity by using digital panoramic radiographs.

Methods: We compared the dental maturity assessed by calcification of mandibular canine, first premolar, second premolar, and second molars using digital panoramic radiographs and skeletal maturity assessed by cervical vertebral maturation stages using lateral cephalograms and hand-wrist radiographs. Skeletal maturity was assessed using a cervical vertebrae maturation technique; hand-wrist maturity was evaluated using Fishman skeletal maturity indicators. Dental maturity was estimated according to guidelines of Demirjian. Spearman rank-order correlation coefficients were used to determine the correlation between tooth calcification stages and skeletal maturity assessed on panoramic radiographs, lateral cephalograms, and hand-wrist radiographs of 60 patient participants, including 45 boys and 15 girls.

Results: The panoramic radiograph is a reliable tool with which to estimate of growth and development of boys.

Conclusion: The relationship between tooth calcification stages and the skeletal maturity indicators in boys allows clinicians to identify the stage of the pubertal growth from panoramic radiographs. It is appropriate to put these skeletal and dental maturation relationships into daily orthodontic diagnostic practice.

Keywords: Cervical vertebrae maturation indicators, Demirjian index, hand-wrist radiograph, lateral cephalogram, panoramic radiograph, skeletal maturation

The study of stages of development is important for interventional therapies, and treatment of trauma and accidents. It is also helpful in forensic identification. The best way to assess the growth and development is to assess skeletal maturity. Radiographs are effective tools for assessing bone maturity in dentistry. During growth, every bone goes through a series of ossification changes that can be

seen radiologically. There are some exceptions, but the events are reproducible enough to provide a basis for comparison between different individuals [1]. Use of radiographs for assessing skeletal maturity was first seen in the early 20th century when hand-wrist radiographs were used. Many authors have used sequential radiographs of growing hand and wrist to evaluate skeletal maturation [2]. The appraisal of the skeletal maturity of a patient is a key factor for timing of treatment. Several other biological indicators of skeletal maturity have been used including increase in height, hand-wrist maturation, and cervical vertebral maturation [3].

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An understanding of growth and maturation is an important factor in diagnosis, treatment, and prognosis during orthodontic intervention. The pubertal growth spurt causes a marked acceleration in the rate of growth of adolescents. Every skeletal and muscular dimension seems to be involved during this marked acceleration of growth. It is considered to be an advantageous period for certain types of treatment. According to Hagg and Taranger the average pubertal growth spurt begins at 10 years for girls and 12.1 years for boys [4]. Maturational status, whether the growth spurt of the patient has been reached or was completed, has considerable influence in treatment planning [5]. Prediction of the timing and the amount of active growth of the craniofacial complex is useful to the orthodontist. This is especially true when considerations are based strongly on facial growth, such as with extra oral traction, functional appliances, selection of orthodontic retention devices, and orthognathic surgery [6].

Many investigators have indicated that chronological age is not a reliable indicator by which to evaluate the maturity of a child. Chronological age may have little or no place in the assessment of the maturational state of a child, and it is not a critical factor in the evaluation of overall growth potential [7]. The developmental status of a child is best estimated relative to specific stages of physiological maturity indices: somatic, skeletal, dental, and sexual maturity [8].

Pyle introduced the idea of using the size and shape of the radiographic shadows of growing bones as indicators of rate of growth and maturity [9]. The hand and the wrist possess many bones and epiphyses that mature in a well-defined progression over time, and which are easily evaluated on a single radiograph. Hand-wrist maturation has become a standardized and extensively studied method for the assessment of skeletal age because of the sequence of recognizable developmental stages and the ease with which radiographs can be obtained. The progression of events might therefore provide not just an assessment of developmental status, but in addition might be used to predict the patient's growth status during puberty.

Vertebral growth changes in size and shape are also used as maturational indicators. The ossification events in the cervical vertebrae begin during fetal life and continue until adulthood. The shapes of the cervical vertebrae change from birth to full maturity at each level of skeletal development. Therefore, maturational

changes can be observed in the vertebrae during this interval, which covers the period when orthodontic treatment is typically performed in a still growing patient. The cervical vertebrae maturation (CVM) method eliminates additional radiation exposure for orthodontic patients and uses the lateral cephalogram, a film routinely used for diagnosis and treatment planning in orthodontic clinics [10].

Dental maturity can be determined by the stages of tooth eruption or by the stages of tooth formation. Tooth formation is proposed as a more reliable criterion for determining dental maturation. The ease of recognition of dental development stages, together with the availability of periapical or panoramic radiographs in most orthodontic or pediatric practices are advantages in attempting to assess physiological maturity.

If correlation can be found between calcification stages, cervical vertebral maturation and hand-wrist maturity, panoramic imaging can be used as the primary imaging modality for assessing maturity. No additional exposure to radiation is necessary if assessment of skeletal maturity can be performed with routine panoramic radiographs alone. This complies with the ALARA (As Low As Reasonably Achievable) principle.

The aim of the present study was to assess the usefulness of panoramic radiographs as a tool to estimate growth and to evaluate different stages of dental maturity using digital panoramic radiographs by comparing different stages of dental maturity with skeletal maturity.

Materials and methods

The study protocol was approved by the Institutional Ethics Committee, KVG Dental College and Hospital (IEC 30/5/2011 No. 281806).

Sixty patient participants aged 8–16 years were included in the study. Informed written assent was obtained from each patient, and informed written consent was obtained from a parent of each patient included in the study. Participants were randomly selected from patients attending the outpatient clinic of the Department of Oral Radiology.

Methods of collection of data

Digital panoramic radiographs, lateral cephalograms, and hand-wrist radiographs were obtained using a digital panoramic machine, Planmeca Proline XC (Oy, Helsinki, Finland).

Inclusion and exclusion criteria

Inclusion criteria were patients from 8 to 16 years old who had normal dentition, and whose parents gave their written informed consent for their inclusion in the study. Exclusion criteria comprised deformed images affecting estimation of tooth development and/or skeletal maturity stages, hypodontia, oral pathology, missing mandibular canine, premolars and second molars, patients who had history of systemic disease that could affect the presence and development of mandibular permanent teeth, patients who had undergone orthodontic treatment, and those who had a history of trauma or injury to the face or hand and wrist regions.

Dental maturity assessment

Dental maturity was assessed according to the calcification stages of individual teeth proposed by Demirjian et al. [11]. The developmental stages of the left mandibular permanent canines, first and second premolars, and second molars were rated on an 8-stage scale from A to H.

Skeletal maturity assessment

Skeletal maturity was evaluated using a cervical vertebra maturation (CVM) method clinically improved by Baccetti et al. [12]. The morphology of the bodies of the second (C2), third (C3), and fourth (C4) cervical vertebrae are rated on a 6-level scale from cervical stage CS 1 to CS6.

Skeletal maturity evaluated by hand-wrist radiographs

Each hand-wrist radiograph was assigned a skeletal age by comparing it with the standard plates designed by Greulich and Pyle [13]. Selected ossification events were determined according to the method described by Fishman [14], and modified by Krailassiri et al. [5], to evaluate the stage of skeletal maturation.

All digital radiographs were viewed on the same computer. Stages of tooth formation, cervical vertebra development, and hand-wrist radiographs of each patient participant were assessed independently by 2 trained observers blinded to the chronological age of the patients. To test the reproducibility of assessments 1 month after the initial report, digital panoramic radiographs, and lateral skull cephalograms were reassessed in random order by 2 new observers blinded to the chronological age of the patients.

Statistical analysis

We used Spearman rank-order correlation coefficients to determine the correlation between tooth calcification stages and skeletal maturity assessed on panoramic radiographs, lateral cephalograms, and hand-wrist radiographs. $P < 0.05$ was considered significant.

Results

The sample consisted of 60 patient participants (45 boys and 15 girls). Although inter-examiner values for CVM stages showed moderate agreement and kappa statistics values in general showed good intra- and inter-examiner agreement (**Table 1**).

Cervical vertebrae maturity and dental maturity

In stage CS3, the mean chronological age was 10.75 ± 2.98 years for girls and 12.33 ± 2.33 years for boys. Based on CVM assessment, the mean chronological age of girls was significantly lower than that of boys. This is because the appearance of each stage is consistently earlier in girls than in boys. Spearman rank-order correlation coefficients between the cervical vertebral maturation stages and developmental stages for the 4 teeth, are shown in **Table 2**. All correlations between cervical vertebral and dental maturity stages were statistically insignificant ($P > 0.05$) except for canines in boys, which showed moderate correlation.

Table 1. Inter and intra examiner reliability in assessing various study parameters using Kappa statistics

	Intraexaminer reliability		Interexaminer reliability
	Examiner 1	Examiner 2	
Hand-wrist radiograph	1.000	0.867	0.867
Cervical vertebra maturation	0.688	0.698	0.92
Tooth maturity	0.90	0.732	0.833

Table 2. Spearman correlation coefficients between cervical vertebrae maturation stages and dental maturity stages

	Boys		Girls	
	Correlation coefficient [#]	<i>P</i>	Correlation coefficient [#]	<i>P</i>
Canine	0.33	0.025*	0.29	0.29
First premolar	0.24	0.099	0.33	0.22
Second premolar	0.28	0.056	0.36	0.18
Second molar	0.27	0.07	0.44	0.095

[#]Spearman correlation, **P* < 0.05

At CS1, the E stage of first premolar and F stage of canine in girls had the highest percentage of 75%. F stage of first premolars in boys had the highest percentage at 63%. At CS2, the F stage of canines, and first and second premolars had the highest percentage: 57% for girls, and for boys F stage of canines and G stage of second molars had the highest percentage at 43%. At CS3, the F stage of canines had the highest percentage: 75% for girls. At CS4, the H stage of the first and second premolars had the highest percentage: 67% for boys. In our study population, there were no cases with CVM stages 5 or 6.

Hand–wrist maturity and dental maturity

At the MP3 stage (the middle phalanx of the third finger, the epiphysis equals its diaphysis) mean chronological age for boys was 10.97 ± 1.70 years and for girls it was 9.23 ± 1.23 years. Spearman rank–order correlation coefficients between the developmental stages of the hand and wrist bones and the developmental stages of the 5 individual teeth are shown in **Table 3**. All correlations between

skeletal maturity and dental maturity stages were statistically significant (*P* < 0.05) for boys and statistically insignificant (*P* > 0.05) for girls. The association ranged from 0.44 to 0.51 for the boys. Sequence in order of the lowest to the highest correlation for boys and girls were the canine, the first premolar, the second premolar, and the second molar. The correlation coefficients of second premolars, as well as the second molars, were the highest, and similar in boys indicated by a coefficient of 0.51.

At the MP3 stage, stage F of canines and the first premolars in boys showed the highest percent distribution (54%), whereas all of the remaining teeth had a scattered distribution. For girls, the canine stage F presented the highest distribution (69%) among all of the teeth studied. At the S stage (the first mineralization of the ulnar sesamoid bone), in boys, the H stage of the first and second premolars demonstrated marked distinction of the percent distribution (100%). There was no percent distribution of calcification stages of individual teeth at the S stage for girls.

Table 3. Spearman correlation coefficients between skeletal maturity stages (hand-wrist radiograph) and dental maturity stages

	Boys		Girls	
	Correlation coefficient [#]	<i>P</i>	Correlation coefficient [#]	<i>P</i>
Canine	0.44	0.002*	0.22	0.42
First premolar	0.48	0.001*	0.27	0.32
Second premolar	0.51	0.000*	0.37	0.17
Second molar	0.51	0.000*	0.45	0.09

[#]Spearman correlation, **P* < 0.05

At the MP3 cap stage (the middle phalanx of the third finger, the epiphysis caps its diaphysis), distribution of tooth calcification stages was not seen clearly in all of the teeth in boys and girls, because this category contained few participants. At the DP3u stage, in girls, all the canine, premolars and second molars were in stage F (100%). In boys, the root formation of most of the teeth, with the exception of the second molars, has attained stage H. At the MP3u stage (the middle phalanx of the third finger, complete epiphyseal union), most of the tooth formation of all of the teeth showed stage H calcification. The distribution of the participants according to skeletal and chronological ages for each skeletal maturity stage is presented in **Table 4**.

Discussion

Assessment of skeletal maturity and dental development is a common clinical practice for growth modification, especially in orthodontics and dentofacial orthopedics. It is also useful for age estimation in forensic science [15]. Because of the considerable variation in development among children; chronological age may have little or no role in determination of the maturation stage of a child, and has led to the concept of biological or physiological age. Physiological age is the rate of progress toward maturity and is estimated by somatic, sexual, skeletal, or dental maturity, or a combination of any of these indicators [8, 16, 17].

Although orthodontic treatment is able to modify the jaw growth and improve dentofacial relationships, it is limited by the extent of jaw growth that might

occur. Many investigators have studied the optimal time for treating patients with orthodontic functional appliances and it is well known that periods of accelerated growth can contribute to correct those kinds of skeletal imbalances [18, 19]. The pubertal spurt in growth can be assessed by some indicators such as increase in body height [20, 21], skeletal maturation of the hand and wrist [22], and cervical vertebral maturation [1, 23]. We investigated the correlation between cervical vertebral maturation stages and the calcification stages of various teeth to determine whether there is a correlation between the CVM, hand-wrist maturation stages, and tooth calcification.

Dental maturity assessment

There are a number of standard scales for rating the stage of tooth calcification [24]. The method described by Demirjian et al. [11] was chosen for the present study because the criteria are based on tooth shape and the ratio of root length to crown height, rather than on the absolute length, so that shortened or elongated projections of developing teeth will not influence the reliability of assessment [5]. Demirjian classified tooth mineralization with regard to maturational changes rather than just an increase in the length of the tooth, because of the variety of tooth sizes and radiographic magnifications. This method uses tooth calcification rather than tooth eruption. Panoramic radiographs are used to assess dental maturity because of their availability clarity.

Table 4. Chronological age and skeletal age for patient participants grouped by skeletal maturity indicators

Skeletal maturity stage	n (%)	Chronological age mean age (SD)	Skeletal age mean age (SD)
MP3			
Boy	37 (82)	10.97 (1.70)	11.78 (1.35)
Girl	13 (87)	9.23 (1.23)	8.62 (1.50)
S			
Boy	3 (7)	14 (1.73)	14.33 (1.52)
Girl	0	-	-
MP3CAP			
Boy	1 (2)	11	12
Girl	1 (7)	15	13
DP3U			
Boy	3 (7)	13.33 (2.08)	14 (2)
Girl	1 (7)	10	11
MP3U			
Boy	1 (2)	15	15
Girl	0	-	-

SD = standard deviation

Many studies have reported high correlations between tooth calcification stages and indicators of skeletal maturity [5, 16, 17, 25, 26]. This could allow clinicians to identify pubertal growth stages from panoramic radiographs. Previously it was reported that tooth calcification stages from panoramic radiographs might be clinically useful as a maturity indicator of pubertal growth and that mandibular second molar calcification showed the highest correlation with skeletal maturity [5]. Racial variations in the relationships between calcification stages of individual teeth and skeletal maturity have been reported [5, 7]. Most studies of the dentition have used either mandibular canines [7], or third molars [27, 28], for dental age assessment.

Dental eruption is a fleeting event that is under strongly influenced by environmental variables. The first disadvantage of eruption-based methods is that its exact timing cannot be determined. Moreover, it can be affected by local variables such as systemic diseases and nutrition. Therefore, its reliability is questionable [11]. Use of Demirjian's method in an Indian population has been controversial and studies supporting and against this method have been reported [29].

Skeletal maturity assessment using the CVM method

Lamparski showed that cervical vertebrae were as reliable and as valid as hand-wrist radiographs as indicators of skeletal maturation [23]. Second to sixth cervical vertebrae (C2–C6) were used in this study. The assessment of cervical vertebral maturation method (CVM) has been intensely investigated in recent years. Most scholars agree that changes in cervical vertebrae correlate with stages of growth and development in adolescents. This can be used to predict pubertal growth spurts, especially the peak of mandibular growth. According to the CVM method, cervical stage 1–2 (CS1–CS2) indicates the period before the peak of growth; the pubertal growth spurt comes during cervical stage 3–4 (CS3–CS4); and cervical stage 5–6 (CS5–CS6) is the period after this peak [12, 25]. Like hand-wrist analysis, this cervical staging method has a comparably high reliability and validity. It has the added advantage in that no additional radiation exposure is required. These three vertebrae are usually visible even when a protective radiation collar is worn. Finally, every stage can be identified on a single cephalogram.

In the present study, all correlations between cervical vertebral and dental maturity stages were insignificant ($P > 0.05$), except for canines in boys that showed moderate correlation. A low, but statistically significant correlation was found between tooth calcification stages of canines and cervical vertebrae maturation stage for boys. Coutinho et al. indicated that the maturation of the lower canines is more strongly associated with the pubertal growth spurt than other teeth [25]. Other investigators have suggested that the development of the second premolars and second molars has the highest correlation with skeletal maturation [7, 15, 18]. In the present study, the development of the mandibular canines was significantly correlated with CVM stage in boys. In CS1–CS2, the percentage distribution of stage F was 58%–43%; in CS3 it was 33%.

Skeletal maturity assessment using the hand-wrist maturation method

Skeletal age assessment

The skeletal age for each hand-wrist radiograph was determined according to the method outlined in the atlas of Greulich and Pyle [13], which is quick and relatively easy to learn. It is less time consuming in practice than the bone stage and system of Tanner et al. and shows greater reproducibility between observers [30, 31]. The Greulich and Pyle method seems to be highly practical for clinical use in skeletal age assessment.

Skeletal maturity assessment

In the present study, assessment of skeletal maturity was based on the system of Fishman [14]. This system offers an organized and relatively simple approach to determine the level of maturation. The system uses only 11 anatomical sites located on the phalanges, the adductor sesamoid, and the radius, all of which exhibit consistency in the time of onset of ossification. The Fishman system also has the advantage of excluding carpals from the assessment, because irregularity in the order of onset of ossification occurs more frequently in the carpals than in the metacarpals or phalangeal epiphyses. To facilitate clear discrimination between the stages and to provide a good description relative to growth status, only 5 out of 11 skeletal maturity indicators are used in the system, and were selected in the present study. The MP3 stage appears during the onset of accelerating growth rate. The S and the MP3 cap stages become

visible during a period of very rapid growth rate. The DP3u and MP3u stages coincide with the time of decelerating growth rate.

The mean age for each skeletal maturity level presented indicated that girls mature earlier than boys. This finding confirms the well-known information in the literature [4, 14, 32, 33]. The study population seemed to be more advanced in chronological age than skeletal age. Cole et al. explained that there are 3 sources of discrepancy between skeletal age and chronological age including variation between individuals in rates of skeletal maturation, the systematic error inherent in the method used to assess skeletal age, and variation between different observers [31].

We found a significant correlation between tooth calcification stages and hand maturity stage for boys. Tooth calcification stages of mandibular second premolars and second molars showed the highest correlation. The E stage of second molars and F stage of second premolars coincided with the MP3 stage and indicated the onset of a period of accelerating growth. Similar results were obtained by Krailassiri et al. [5] and Kumar et al. [15]. Chertkow [7] and Chertkow and Fatti [16], showed a close relationship between mandibular canine calcification stage G and various skeletal indicators of the pubertal growth spurt.

The relationship between skeletal maturity and peak adolescent height velocity (PHV) is well established. Bjork [33] found that capping of epiphyses of third middle phalanx was very closely related to the age of pubertal maximum growth velocity. Studies reporting low correlations between dental age and the pubertal growth spurt have found maturity of the canines to be more closely related to PHV than the maturity of other teeth [34].

Compared with the skeletal maturity assessed by CVM, hand-wrist maturity showed better correlation in boys. However, the relationship between skeletal and dental maturity did not show any correlation in girls. The E stage of mandibular second molars and F stage of mandibular second premolars designate the onset of accelerating growth rate.

Conclusion

The relationship between tooth calcification stages and skeletal maturity indicators in boys may allow clinicians to more easily identify the stages of pubertal growth from panoramic radiographs. It is appropriate to put these skeletal and dental maturation

relationships into daily orthodontic diagnostic practice. However, further studies with a larger sample size are recommended for more conclusive results. Nevertheless, we suggest that there is diagnostic value in the calcification phases of dentition as indicators of individual skeletal maturity in boys. Further studies using a larger number of girls may yield additional knowledge.

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Conflict of interest statement

The authors have no conflicts of interest to declare.

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