

Co-Relation Between Determination Of Skeletal Maturation Using Cervical Vertebrae And Dental Calcification Stages

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Citation

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Abstract

Assessment of skeletal maturity and dental development is a common clinical practice in many health professions especially for age estimation in forensic sciences and for growth modification in orthodontics & dentofacial orthopedics. The purpose of this study was to investigate the relationships between the calcification stages of various teeth and skeletal maturity stages using cervical vertebrae among Indians individuals. The study subjects consisted of 46 male subjects and 54 female subjects ranging in age from 9 to 18 years. A total of 100 dental panoramic radiographs and lateral cephalograms were obtained and analyzed. Calcification stages of the mandibular dentition (canines, first premolars, second premolars, second molars and third molars) were rated according to the system of Demirjian. Skeletal age and skeletal maturity stages [cervical vertebrae maturity indicators-(CVMI)] were determined by using the method of Hasal and Farman. Statistically significant relationships were determined between dental calcification and skeletal maturity stages according to Spearman rank-order correlation coefficients. Correlations between dental development and skeletal maturity ranged from 0.403 to 0.758 for males and 0.419 to 0.811 for females ($P < 0.01$). The second molar showed the highest correlation and the third molar showed the lowest correlation for male and female subjects. Stage F of tooth calcification corresponded to onset of PHV (stage 2 of CVMI) & Stage G of tooth calcification in canine; first premolar and second molar (except for second premolars in males) corresponded to peak of pubertal growth spurt (stage 3 of CVMI). Root formation of the canine as well as the first premolar was completed in the majority of the subjects at stage 5 of CVMI. For all the teeth except third molar root formation was completed at stage 6 of CVMI. Because of the high correlation coefficients, this study suggests that tooth calcification stages from panoramic radiograph (which is a routine diagnostic radiograph for orthodontic treatment) may be clinically useful as a maturity indicator and in age estimation.

INTRODUCTION

Assessment of skeletal maturity and dental development is a common clinical practice in many health professions especially for age estimation in forensic sciences and for growth modification in orthodontics & dentofacial orthopedics. On the other hand chronological age may have little or no role in the assessment of the maturation stage of child.^{1,2,25} Timing of the orthopedic growth modification therapy is typically linked with the individual's peak of skeletal maturity to maximize the growth potential^{3,4} Evaluation of the skeletal age can provide additional information that can contribute for this decision. Hand-wrist radiography is recognized as a reliable parameter to evaluate the skeletal age of a patient.⁵⁻⁹ Hassel and Farman¹⁰ observed the bodies of cervical vertebrae (C_2 , C_3 and C_4) in lateral cephalograms, and evaluated their skeletal maturity [cervical vertebrae maturity indicators-(CVMI)] through a correlation with the Fishman method⁷ which, in turn, evaluates skeletal hand-wrist maturation with a Skeletal Maturity Indicator

(SMI) system developed by him.

Dental development has been widely investigated as a potential predictor of the skeletal maturity level^{1, 11-18}. Generally, the dental development can be assessed by either the phase of tooth eruption or the stage of tooth calcification, with the latter being more reliable.¹⁹⁻²¹ The ability to assess skeletal maturity by the developmental stage of the dentition through the examination of a panoramic radiograph (orthopantomograph) and relating them with CVMI from lateral cephalograms (both of which are routine diagnostic radiographs for orthodontic treatment) offers several advantages over the conventional hand-wrist radiographic method. Generally, Orthodontists are more familiar with the panoramic radiographs and lateral cephalograms than with the hand-wrist radiograph. Also, keeping in mind ALARA (As Low as Reasonably Achievable) principle, no additional exposure to radiation would be necessary if skeletal maturity can be accessed through routinely taken radiographs.

Racial variations in the relationship have also been suggested.^{1,22,23} Mappes et al²⁴ indicated that the predominant ethnic origin of the population, climate, nutrition, socioeconomic levels, and urbanization are causative factors of these racial variations. At the start of this study, we thought that Indian subjects may have a rhythm of skeletal and dental maturation during pubertal development that is different from that of children from other countries from whom the standards were derived. Therefore, the aim of this study was to investigate the relationships between the stages of calcification of various teeth and the stages of skeletal maturity among Indian individuals.

MATERIALS AND METHODS

MATERIALS SELECTION

This descriptive study was designed as a cross-sectional research project. Panoramic and lateral cephalometric radiographs of 100 Indian subjects (M: F:: 46:54) were obtained from the pre-treatment records of patients attending the clinics for orthodontic treatment. The inclusion in the study was set to include only those individuals who presented with the following criteria:

1. Chronological age ranging from 9 to 18 years.
2. Free of any serious illness.
3. Normal overall growth and development
4. No abnormal dental condition, e.g. impaction, transposition and congenitally missing teeth.
5. No previous history of trauma or disease to the face & neck.
6. No history of orthodontic treatment.
7. Had not had extraction of any permanent teeth

ASSESSMENT OF PARAMETERS:

All assessments were performed in a darkened room with a radiographic illuminator to ensure contrast enhancement of the bone and tooth images.

The assessment of dental maturation from the panoramic radiographs was based on the left mandibular teeth (canines, first premolars, second premolars, second molars and third molars) and following the method described by Demirjian et al.¹⁹, in which eight stages of calcification from A to H are described for each tooth. (In case of any missing left

mandibular teeth, the right teeth corresponding to the missing teeth were substituted. Mandibular incisor and first molars were not rated because apical closure had already take place).

Stage A: In both uniradicular and multiradicular teeth, a beginning of calcification is seen at the superior level of the crypt. No fusion of these calcified points can be observed.

Stage B: Fusion of the calcified points forms one or several cusps which unite to give a regularly outlined occlusal surface.

Stage C: Enamel formation has been completed at the occlusal surface, and dentine formation has commenced. The pulp chamber is curved, and no pulp horns are visible.

Stage D: Crown formation has been completed to the level of the cemento-enamel junction. Root formation has commenced. The pulp horns are beginning to differentiate, but the walls of the pulp chamber remain curved.

Stage E: The root length remains shorter than the crown height. The walls of the pulp chamber are straight, and the pulp horns have become more differentiated than in the previous stage. In molars, the radicular bifurcation has started to calcify.

Stage F: The walls of the pulp chamber now form an isosceles triangle, and the root length is equal to or greater than the crown height. In molars, the bifurcation has developed sufficiently to give roots a distinct form.

Stage G: The walls of the root canal are now parallel, but the apical end is still partially open.

Stage H: The apical end of the root canal is completely closed and the periodontal membrane is uniform around the root and the apex.

Assessment of skeletal maturation from the lateral cephalograms was based on the maturation of bodies of cervical vertebrae (C₂, C₃ and C₄) and following the method described by Hasal and Farmen¹⁰ in which six stages of skeletal maturation are described (CVMI).

Stage 1 (Initiation): Corresponds to the combination of Fishman's stages 1 and 2 and to beginning of adolescent. Great amount of pubertal growth expected (80 to 100 %). Inferior borders of C₂, C₃ and C₄ are flat at this stage. The vertebrae are wedge shaped, and the superior vertebral

borders are tapered from posterior to anterior.

Stage 2 (Acceleration): Corresponds to the combination of Fishman's stages 3 and 4. Growth acceleration begins at this stage. Significant pubertal growth expected (65% to 85%). Concavities are developing in the inferior borders of C₂ and C₃. The inferior border of C₄ is flat. The bodies of C₃ and C₄ are nearly rectangular in shape.

Stage 3 (Transition): Corresponds to the combination of Fishman's stages 5 and 6 and acceleration of growth towards peak height velocity. Moderate pubertal growth expected (25% to 65%). Distinct concavities are seen in the inferior borders of C₂ and C₃. A concavity is beginning to develop in the inferior border of C₄. The bodies of C₃ and C₄ are rectangular in shape.

Stage 4 (Deceleration): Corresponds to the combination of Fishman's stages 7 and 8 and to deceleration of adolescent growth spurt. Reduced expectation of pubertal growth (10 to 25%). Distinct concavities are seen in the inferior borders of C₂, C₃ and C₄. The vertebral bodies of C₃ and C₄ are becoming more square in shape.

Stage 5 (Maturation): Corresponds to the combination of Fishman's stages 9 and 10. Final maturation of the vertebrae took place during this stage. Insignificant pubertal growth expected (5 to 10%). More accentuated concavities are seen in the inferior borders of C₂, C₃ and C₄. The bodies of C₃ and C₄ are nearly square to square in shape.

Stage 6 (Completion): Corresponds to the combination of Fishman's stages 11. Pubertal growth completed at this stage (little or no growth expected) Deep concavities are seen in inferior border of C₂, C₃ and C₄. The bodies of C₃ and C₄ are square or are greater in vertical dimension than in horizontal dimension.

Radiographic assessments for dental and skeletal maturity were performed simultaneously using an illuminated viewing box in a dark room by two trained dentists, with a single examiner performing all the dental maturation assessment while the other was assessing the skeletal maturity stage of all lateral cephalograms. The interpretations of panoramic and cephalometric radiographs were discussed until agreement was reached. Exact chronological ages were verified by reference to the patient's birth date.

STATISTICAL ANALYSIS

All statistics were performed using the SPSS software package (version 10, SPSS Inc., Chicago, IL, USA). Descriptive statistics were obtained by calculating the means and standard deviations of the chronological ages for the six stages of CVMI. To study the relationship between the stage of mineralization of the teeth and the stage of CVMI, the percentage distribution of the stages of calcification for each tooth was calculated. The Spearman rank order correlation coefficients were estimated to measure the association between CVMI and dental calcification stages of individual teeth, and the statistical significance of the correlation was tested. To evaluate the reproducibility of the interpretation, the first and second skeletal and dental maturity assessments were tested using a Spearman Brown formula.

To test the reproducibility of the assessments of skeletal maturity and dental development stage, the same two investigators reevaluated randomly selected lateral cephalograms and panoramic radiographs from 15 of the same male and female subjects eight weeks after the first evaluation. The differences between double interpretations were statistically tested.

RESULTS

The distribution of chronological ages for all the subjects, grouped by skeletal maturity indicators, is shown in Table 1. The appearance of each stage is consistently earlier in female subjects than in the male subjects. The reproducibility of all the assessments was found to be good, with high coefficient values. The coefficients of reliability were found to be between .921 and .989 for the dental calcification stage assessments and between .945 and .99 for the CVMI assessments.

Figure 1

Table 1: Mean and standard deviation (SD) of chronological ages for all Subjects Grouped by Cervical vertebrae maturity Indicator (CVMI) stages

CVMI stages	Male (Age in years)		Female (Age in years)	
	Mean	SD	Mean	SD
Stage 1	11.8	1.89	9.5	0.71
Stage 2	12.1	1.69	11.7	1.21
Stage 3	14.5	0.71	12.5	0.71
Stage 4	15.40	0.58	13.7	0.58
Stage 5	17.50	1.29	15.1	1.54
Stage 6	18.33	1.53	16.7	1.53

Spearman rank-order correlation coefficients between the CVMI and the developmental stages of the five individual teeth are shown in Table 2. All the correlations between CVMI and dental stages were statistically significant at the $P < 0.01$ significance level. The correlations ranged from .403 to .758 for males and from .419 to .811 for females. In both male & female subjects, the tooth sequence in order of the lowest to the highest correlation was third molar, canine, first premolar, second premolar, and second molar. The second molar showed the highest correlation, as indicated by an r value of .758 and .811 ($P < 0.01$) for male and female subjects, respectively. The third molar showed the lowest correlation for both sexes ($r = .403$ for male subjects, and $r = .419$ for female subjects).

Figure 2

Table 2: Correlation coefficients between CVMI and dental development stages in male and female subjects.

Tooth	Correlation Coefficients (r)	
	Male	Female
Canine	0.621	0.653
First Premolar	0.645	0.784
Second Premolar	0.667	0.795
Second Molar	0.758	0.811
Third Molar	0.403	0.419

$P < 0.01$

The percentage distributions of the stages of calcification for each of the studied teeth are shown in Table 3. Sex differences in the pattern of mineralization of the various teeth were noted.

Figure 3

Table 3: Percentage distribution (%) of calcification stages of each of the studied teeth

Stages	Canine		First Premolar				Second premolar				Second Molar				Third Molar							
	Male		Female		Male		Female		Male		Female		Male		Female		Male		Female			
	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%	n	%		
A																	5	10.9	11	20.4		
B																			4	7.4		
C																			13	28.3	11	20.4
D	2	4.3			2	4.3	2	3.7	1	2.2	2	3.7	1	2.2	4	7.4	23	50.0	16	29.6		
E			3	5.6									4	8.7	10	18.5	2	4.3	7	13.0		
F	17	37.0	10	18.5	16	34.8	19	35.2	22	47.8	23	42.6	19	41.3	21	38.9	2	4.3				
G	11	23.9	21	38.9	8	17.4	10	18.5	7	15.2	11	20.4	7	15.2	4	7.4			5	9.3		
H	16	34.8	20	37.0	20	43.5	23	42.6	16	34.8	18	33.3	15	32.6	15	27.8	1	2.2				
Total	46	100	34	100	46	100	34	100	46	100	34	100	46	100	34	100	46	100	34	100		

The percentage distribution of the stages of calcification for each of the teeth studied and the stages of CVMI was calculated. These findings are shown in Tables 4 through 9. Because of poor correlation of third molar with CVMI, data for the third molars was tabulated in separate table (Table 10).

In female subjects, the canine stage E showed the highest percent distribution (66.7%) at stage 1 of CVMI (Table 4). For male subjects, the second premolar stage F showed the highest percent distribution (75%) at stage 1 of CVMI. For female subjects, the second molar stage D and E and second premolar stage D and F had equal percentage distribution (50%). All the remaining teeth had a scattered distribution.

Figure 4

Table 4: Percentage distribution of calcification stages of individual teeth at CVMI Stage 1

Stages	Canine		First Premolar		Second Premolar		Second Molar	
	Male	Female	Male	Female	Male	Female	Male	Female
D	25.00		33.33	33.33	25.00	50.00	25.00	50.00
E	25.00	66.70	33.33	33.33			50.00	50.00
F	50.00	33.30	33.33	33.33	75.00	50.00	25.00	

At stage 2 of CVMI (Table 5), high distribution of tooth calcification stage F for both male and female subjects. In female subjects, the stage F showed the highest percent distribution (83.3%) for first and second premolar. Whereas, in male subjects, the same stage F showed the higher percent distribution for second premolar (88.89%), first premolar (75%), canine (71.43%) and the second molar (66.67%).

Figure 5

Table 5: Percentage distribution of calcification stages of individual teeth at CVMI Stage 2

Stages	Canine		First Premolar		Second Premolar		Second Molar	
	Male	Female	Male	Female	Male	Female	Male	Female
D								11.11
E			25.00		11.11		11.11	22.22
F	71.43	33.33	75.00	83.33	88.89	83.33	66.67	33.33
G	14.29	66.67		16.67		16.67	11.11	
H	14.28						11.11	

All of the studied teeth were dispersed among the F and G calcification stages at Stage 3 of CVMI (Table 6). In male subjects, the canine and second molar showed the 100% distribution in G stage whereas; second premolar showed 100% distribution in F stage. In females canine showed the highest percentage (66.67%) in G stage of tooth calcification.

Figure 6

Table 6: Percentage distribution of calcification stages of individual teeth at CVMI Stage 3

Stages	Canine		First Premolar		Second Premolar		Second Molar	
	Male	Female	Male	Female	Male	Female	Male	Female
F		33.33	50.00	50.00	100.00	50.00		50.00
G	100.00	66.67	50.00	50.00		50.00	100.00	50.00

At stage 4 of CVMI (Table 7), in male subjects, the canine, second premolar and second molar stage G showed the highest percent distribution (66.67%), whereas in females second premolar and the second molar stage G showed the highest percent distribution (66.67%).

Figure 7

Table 7: Percentage distribution of calcification stages of individual teeth at CVMI Stage 4

Stages	Canine		First Premolar		Second Premolar		Second Molar	
	Male	Female	Male	Female	Male	Female	Male	Female
E								33.33
F		33.33	33.33	25.00	33.33	66.67	33.33	66.67
G	66.67	66.67	33.33	50.00	66.67	33.33	66.67	
H	33.33	0.00	33.33	25.00				

For both sexes, root formation of the canine as well as the first premolar was completed (stage H) in the majority of the subjects (75–90%) at stage 5 CVMI (Table 8). 77.78% of female subject for second premolar and 75% of male subject for second molar had exhibited stage H.

Figure 8

Table 8: Percentage distribution of calcification stages of individual teeth at CVMI Stage 5

Stages	Canine		First Premolar		Second Premolar		Second Molar	
	Male	Female	Male	Female	Male	Female	Male	Female
F					25.00			33.33
G	25.00	11.11	25.00	11.11	25.00	22.22	25.00	11.11
H	75.00	88.89	75.00	88.89	50.00	77.78	75.00	55.56

All the studied teeth in male subjects and the canine and the first premolars in female subjects had completed root formation at stage 9 of CVMI (Table 9).

Figure 9

Table 9: Percentage distribution of calcification stages of individual teeth at CVMI Stage 6

Stages	Canine		First Premolar		Second Premolar		Second Molar	
	Male	Female	Male	Female	Male	Female	Male	Female
H	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Third molars have been showing the variable distribution in various subjects of males and females.

Figure 10

Table 10: Percentage distribution of calcification stages of third molar at various CVMI Stages

Stages	Stage 1		Stage 2		Stage 3		Stage 4		Stage 5		Stage 6	
	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female	Male	Female
A	25.00	50.00	22.22	66.67		50.00						
B	25.00			16.67				33.33				
C	25.00	50.00	55.56	16.67				33.33	25.00	11.11		
D	25.00		22.22		100.00	50.00	100.00	33.33	50.00	44.44	33.33	33.33
E									25.00	22.22		33.33
F												33.33
G										22.22		33.33
H												33.33

DISCUSSION

The development status of an individual is usually assessed in relation to physical events that take place during the progress of growth like skeletal ossification stages, the attainment of peak growth velocity, pubescent changes in the body, or dental calcification stages. Indicators of developmental age are therefore more informative than chronological age, particular for age estimation and clinical application²⁵ (Growth modification treatment with functional appliances to displace the mandible/ change its direction of growth, extra oral orthopaedic appliances such as headgear to restrict or protract the maxilla and decision regarding proper timing of orthognathic surgery).

Conventional prediction schemes of maturation indicators would overestimate the developmental stage of the child and, consequently, underestimate the growth potential.²⁶ Conversely, comparisons of a child’s status against

published standards from other countries^{27,28} may overestimate a patient's degree of developmental delay^{29,30} or the precocity.^{31,32} Racial variations in the relationships between the calcification stages of individual teeth and skeletal maturity have been reported previously.^{1,22-24} Therefore, this study was carried out to investigate the relationship between the stages of calcification of various teeth and skeletal maturity stages using CVMI among Indian individuals.

It has long been contended that dental eruption, which is the most conspicuous and easily determined indicator of dental maturation, is much more variable in its timing than skeletal maturation.^{20,33} According to Nolla,²⁰ dental eruption has also been reported to be more variable than the calcification sequence in the dentition. Dental eruption is a fleeting event that is under greater environmental influence.¹⁹ In the present study, calcification stages of teeth instead of eruption were preferred because tooth formation is proposed as a more reliable criterion for determining dental maturation.²⁰ Therefore, the dental maturity assessment stages of Demirjian et al¹⁹ were used. This Demirjian's method also shows high accuracy when applied to north Indian population.³⁴ This method's criterion consists of distinct details based on shape criteria and proportion of root length, using the relative value to crown height, rather than on absolute length. Therefore, foreshortened or elongated projections of developing teeth will not affect the reliability of assessment.²² Panoramic radiograph was selected over intraoral periapical radiographs to study the stages of calcification because multiple teeth were included in this study, clear visibility of the image of the area required and less radiation exposure.

Various areas of skeleton has been used for assess to skeletal maturity viz. the foot, the ankle, the hip, the elbow ,the hand wrist and the cervical vertebrae. Hand-wrist radiography is recognized as a reliable parameter to evaluate the skeletal age of a patient.⁵⁻⁹ Hassel and Farman¹⁰ observed the bodies of cervical vertebrae (C₂, C₃ and C₄) in lateral cephalograms, and evaluated CVMI through a correlation with the Fishman method⁷ which, in turn, evaluated SMI using hand-wrist radiographs. In present study CVMIs were evaluated using lateral cephalograms, which are routine diagnostic radiograph for orthodontic treatment.

Many studies reported that the high correlations between the tooth calcification stages and the skeletal maturity indicators probably allow the clinician to more easily identify the

stages of the pubertal growth period from the panoramic radiograph^{12, 16, 17, 22, 23, 35-38}. On the other hand, Lewis and Garn¹³, Garn et al³⁹, and Tanner⁴⁰ have reported low or insignificant correlations between the level of skeletal and dental maturation. The lack of concordance among the results of previous studies may be attributed, at least in part, to the different methods used for assessing skeletal and dental maturity. Because the similar methods and same population were used, in the studies of B. Rai et al^{35,36} we compared most of our results with the their findings and the results are significantly correlated. We also found similar trends from the studies done in Turkish subjects²³ and Thai individuals.¹²

The mean chronological age for each skeletal maturity level shown in Table 1 indicated that the appearance of each CVMI stage is consistently earlier in the females than in the males, and this finding was in accordance with the information published in several studies.^{22,41,42} Correlation coefficients between skeletal and dental maturity stages of subjects are shown in Table 2. These correlation coefficients indicate that the second molars show the highest relationship and the third molars show the lowest correlation for both sexes among Indian subjects. Which are in concordance with the findings of B. Rai et al^{35,36} among north Indian subjects and with the findings of Uysal T. et al²³ among Turkish subjects. However, in male and female Thai individuals, the second premolar teeth showed the highest correlation coefficients between skeletal and dental development stages.¹²

Tooth mineralization relative to stages of skeletal maturation is considered separately for male and female subjects. The relationship between skeletal maturity and PHV is well established.^{7,8,41,42} Hagg U⁸ & Bjork⁴¹ found appearance of adductor sesamoid of thumb makes the beginning of pubertal growth spurt [onset of peak height velocity(PHV)] which corresponds to Stage 2 of CVMI (Fishman's SMI 4). At stage 2 of CVMI, all the studied teeth showed the highest percentage distribution for tooth calcification stage F in all the subjects. We may infer stage F of tooth calcification corresponds to onset of PHV.

Bjork⁴¹ found that MP3cap stage was very closely related to the age of pubertal maximum growth velocity which corresponds to Stage 3 of CVMI (Fishman's SMI 6). Most of the studied teeth (Except the second premolars in males which were still in F stage) were in G stage of tooth calcification only at Stage 3 of CVMI. This infers stage G of

tooth calcification in canine; first premolar and second molar may correspond to peak of pubertal growth spurt.

Studies reporting low correlations between dental age and the pubertal growth spurt have found the maturity of the canines to be more closely related to PHV than to the other teeth.^{17,43} The relationship between calcification of the canine and skeletal maturity indicators was quite high, .621 for males and .653 for females, in our study. The findings of Chertkow and Fatti¹⁷ and Chertkow¹ show a close relationship between mandibular canine calcification stage G and various skeletal indicators of the pubertal growth spurt. These investigators found that the mandibular canine stage G coincided with the early appearance of the adductor sesamoid bone (stage 2 of CVMI) in 77% of their male and female samples. Where as in our study 100 % of canines in males and 66.67% of canines in females were in stage G at stage 3 of CVMI.

Krailassiri et al¹² suggested that the interpretation of the relationship between the stage of dental and skeletal development of the canine teeth and the late stages of skeletal maturity was not meaningful because they found that a large number of canines and first premolars had already attained apical closure since the MP3cap stage for males and DP3u stage onward for females. In this study, root formation of the canine as well as the first premolar was completed in the majority of the subjects at stage 5 of CVMI and for all the teeth except third molar was completed at stage 6 of CVMI, supporting the suggestions of Krailassiri et al.¹²

CONCLUSION

The appearance of each skeletal stage is consistently earlier in the females than in the males. In Indian subjects, the tooth sequence in order of the lowest to the highest correlation for male and female subjects was third molar, canine, first premolar, second premolar, and second molar. The second molar showed the highest and the third molar showed the lowest relationship for male and female subjects.

Stage F of tooth calcification may correspond to onset of PHV (stage 2 of CVMI) & Stage G of tooth calcification in canine; first premolar and second molar may correspond to peak of pubertal growth spurt (stage 3 of CVMI). Root formation of the canine as well as the first premolar was completed in the majority of the subjects at stage 5 of CVMI. For all the teeth except third molar root formation was completed at stage 6 of CVMI.

Because of the high correlation coefficients, this study suggests that tooth calcification stages from panoramic radiographs (which are a routine diagnostic radiograph for orthodontic treatment) might be clinically useful in age estimation and as a maturity indicator with a degree of confidence similar to some of the other indicators described in the use of the hand-wrist radiograph or lateral cephalogram. It is appropriate to put this CVMI and dental maturation relationships into daily orthodontic diagnostic practice.

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