Original Article

Relationships Between Dental Calcification Stages and Skeletal Maturity Indicators in Thai Individuals

Suleekorn Krailassiri, DDS; Niwat Anuwongnukroh, DDS, MSD; Surachai Dechkunakorn, DDS, D Ortho

Abstract: The purpose of this study was to investigate the relationship between the stages of calcification of various teeth and skeletal maturity stages among Thai individuals. The study subjects consisted 139 male subjects and 222 female subjects ranging in age from 7 years to 19 years. A total of 361 hand-wrist and panoramic radiographs were obtained and analyzed. The tooth development of the mandibular canines, first and second premolars, and second and third molars were assessed according to the Demirjian's system. Skeletal age and skeletal maturity stages were determined from hand-wrist radiographs by using the method outlined in the atlas of Greulich and Pyle and the Fishman's system, respectively. The Spearman rank order correlation coefficient revealed significant relationships (r = 0.31–0.69, $P < .01$) between dental calcification stages and skeletal maturity stages. The second premolar was the tooth showing the highest correlation (r = 0.66 in male subjects, r = 0.69 female subjects). The third molar demonstrated the poorest correlation (r = 0.47 in male subjects, r = 0.31 in female subjects). The canine stage F for both sexes (63.2% for female subjects, 54.1% for male subjects) coincided with the MP_3 stage. The second molar stage E for female subjects (51.4%) and stage G for male subjects (66.7%) were related to the S stage and the MP_{3cap} stage, respectively. This suggests that tooth calcification stages from panoramic radiographs might be clinically useful as a maturity indicator of the pubertal growth period. However, further study is recommended in a larger sample size, and future studies should address development of the canines and second molars. (*Angle Orthod* 2002;72:155–166.)

Key Words: Tooth calcification; Skeletal maturation; Pubertal growth period; Hand and wrist radiograph

INTRODUCTION

It is important to know the stage of maturation of a patient. Assessing maturational status, whether the pubertal growth spurt of that patient has been reached or completed, can have a considerable influence on diagnosis, treatment goals, treatment planning, and the eventual outcome of orthodontic treatment. This is especially true when clinical considerations are based strongly on the increased or decreased rates of craniofacial growth, such as the timing and use of extraoral traction, the use of functional appliances, extraction vs nonextraction, the selection and execution of orthodontic retention, and the timing of orthognathic surgery.[1–6]

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Considerable variations in the development among children of the same chronological or calendar age have led to the concept of biologic or physiologic age. Physiologic age is the registry of the rate of progress toward maturity that can be estimated by somatic, sexual, skeletal, and dental maturity.[7–10]

Somatic maturity is recognized by the annual growth increments in height or weight.[7] The changes of secondary sex characteristics, voice changes in boys and menarche in girls, are characterized as sexual maturity.[7] The usefulness of the 2 maturity indicators has limited value for the immediate clinical judgment of a patient's maturity stage because these indicators can be applied only after the serial recording of height or the inception of puberty.

The technique for assessing skeletal maturity consists of visual inspection of the developing bones — their initial appearance and their subsequent ossification-related changes in shape and size. Various areas of the skeleton have been used: the foot, the ankle, the hip, the elbow, the hand-wrist, and the cervical vertebrae.[11] The hand-wrist radiograph is commonly used for skeletal developmental assessment. Most investigators have found significant correlation

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among maturation stages derived from hand-wrist radiographs, changes in height during pubertal growth period, and facial growth.[4,6,12–15]

The last physiologic measure is dental maturity, which can be determined by the stage of tooth eruption or the stage of tooth formation. The latter is proposed as a more reliable criterion for determining dental maturation.[16–18]

If a strong association exists between skeletal maturity and dental calcification stages, the stages of dental calcification might be used as a first-level diagnostic tool to estimate the timing of the pubertal growth spurt. The ease of recognizing dental developmental stages, together with the availability of intraoral or panoramic radiographs in most orthodontic or pediatric dental practices, are practical reasons for attempting to assess physiologic maturity without resorting to hand-wrist radiographs.

Relationships between the calcification stages of individual teeth and skeletal maturity have been previously reported. Racial variations in the relationships have also been suggested. Unfortunately, little is known of this relationship in Thai children and adolescents. The objective of this study was to investigate the relationships between the stages of calcification of various teeth and skeletal maturity stages among Thai individuals. The findings from this study will establish a valid clinical tool for indicators of the pubertal growth period in Thai children, adolescents, and young adults without the necessity of resorting to hand-wrist radiographs.

MATERIALS AND METHODS

This research was designed as a cross-sectional descriptive study. The samples were derived from dental panoramic and hand-wrist radiographs of 139 male and 222 female subjects registered as patients at the Orthodontic Department, Faculty of Dentistry, Mahidol University. Either a left or a right hand-wrist radiograph was used according to the study of Dreizen et al[19] and Wenzel et al.[20]

The selection criteria included:

- The subjects were all Thais, well nourished, and free of any known serious illness.
- The subjects had undergone neither previous orthodontic treatment nor extraction of any permanent teeth.
- The subjects had normal dental conditions, for example, no impaction or transposition of teeth.
- The subjects had no previous history of trauma or injury to the face and the hand and wrist regions.

Assessment of dental calcification stage

From several investigations,[17,21–23] the tooth calcification of homologous teeth was found to be symmetrical; therefore, only left mandibular teeth in panoramic radiographs were examined. In the case of any missing left mandibular teeth, the right teeth corresponding to the missing teeth were substituted. The maxillary posterior teeth were omitted from the study because superimposition of calcified structures in this area resulted in inaccurate assessment of the stage of development of these teeth. Mandibular incisors as well as first molars were not rated because apical closure had already taken place. The teeth examined were thus the mandibular canines, the first and second premolars, and the second and third molars.

Tooth calcification was rated according to the method described by Demirjian et al[21] in which one of 8 stages of calcification, A to H, was assigned for each tooth (Figure 1).

Assessment of skeletal age

Each hand-wrist radiograph was assigned a skeletal age by comparing it with the standard plates in the *Radiographic Atlas of Skeletal Development of the Hand and Wrist* (Greulich and Pyle, 1959).[24]

Assessment of skeletal maturity stage

To evaluate the stage of skeletal maturation of each hand-wrist radiograph according to the method described by Fishman,[4] the following selected ossification events were determined:

- MP_3: the middle phalanx of the third finger, the epiphysis equals its diaphysis
- S stage: the first mineralization of the ulnar sesamoid bone
- MP_{3cap}: the middle phalanx of the third finger, the epiphysis caps its diaphysis
- DP_{3u}: the distal phalanx of the third finger, complete epiphyseal union
- MP_{3u}: the middle phalanx of the third finger, complete epiphyseal union

All of the assessments were made simultaneously on an illuminated viewing box in a dark room by 3 examiners. The interpretations of both hand-wrist and panoramic radiographs were discussed until agreement was reached. Exact chronological ages were verified by reference to the patient's birth date.

Reproducibility test

To test the reproducibility of the assessments of skeletal maturity, dental developmental stage, and skeletal age, the same investigators reevaluated randomly selected hand-wrist and panoramic radiographs from 10 of the same male subjects and 10 of the same female subjects 4 weeks after the first evaluation. The differences between double interpretations were statistically tested.

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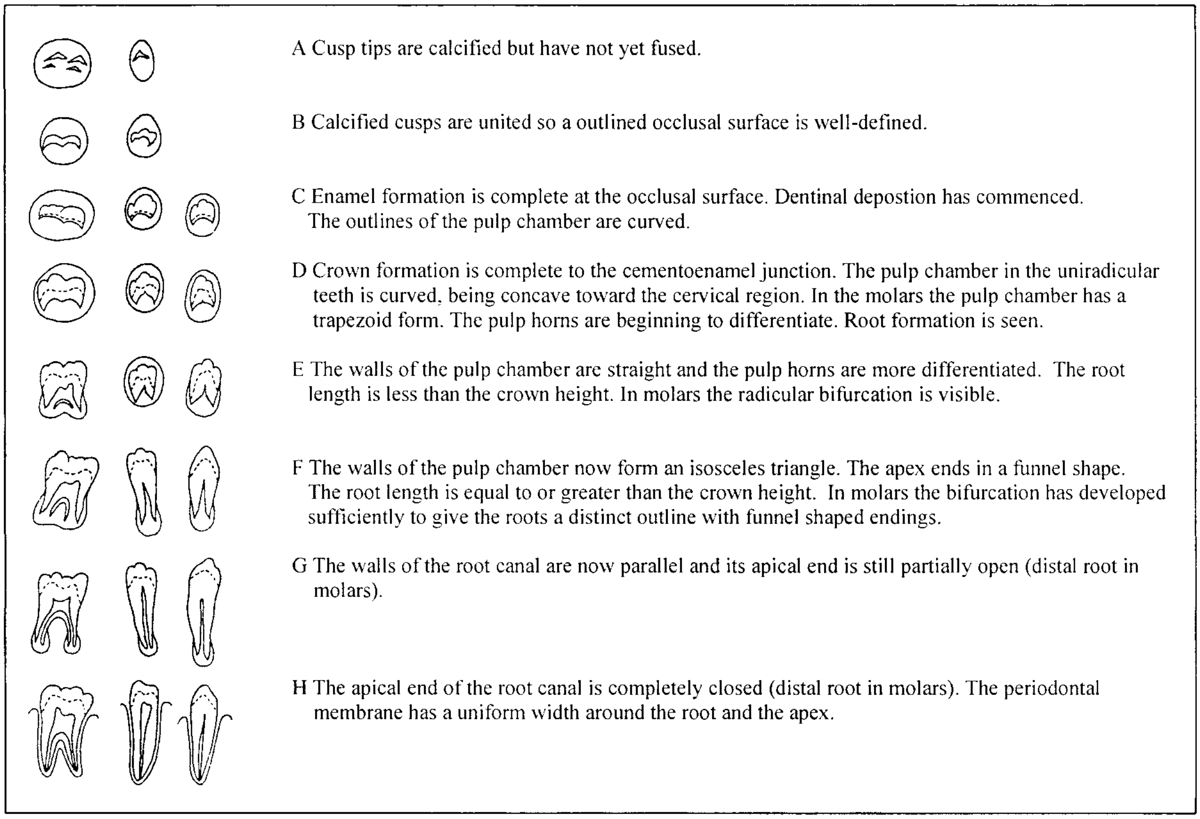

FIGURE 1. Dental calcification stages (adapted from Demirjian et al[21]).

Statistical analysis

The SPSS for Windows release 7.5.1 (SPSS Inc, Chicago, Illinois) was used in calculation of all statistics.

- Descriptive statistics were obtained by calculating the means and standard deviations of the chronological ages and skeletal ages for the 5 stages of skeletal maturity indicators.
- The Spearman rank order correlation coefficient was applied to measure the association between skeletal maturational indicators and dental calcification stages of individual teeth, and the statistical significance of the correlation was tested.
- To study the relationships between the stage of mineralization of the teeth and the stage of skeletal maturation, the percentage distribution of the stages of calcification for each tooth was calculated.
- To evaluate the reproducibility of the interpretation, the first and second skeletal and dental maturity assessments as well as skeletal age assessment were tested using a Spearman Brown formula.

RESULTS

The sample consisted of 139 male and 222 female subjects ranging in age from 7 years to 19 years. The distribution of the study subjects according to skeletal and chronological ages for each skeletal maturity stage is presented in Table 1. The mean ages for each stage of skeletal maturity were consistently younger in female subjects. The mean chronological age of the female group was approximately 1.5 years (range, 1.3 years through 1.8 years) younger than that of the male group.

TABLE 1. Chronological Ages and Skeletal Ages for Study Subjects Grouped by Skeletal Maturity Indicators

Skeletal Maturity Stage	Sex	No. of Subjects	Chronological Age, Mean ± SD, y	Skeletal Age, Mean ± SD, y
MP_3	Male	37	11.2 ± 1.5	11.6 ± 0.6
	Female	19	9.7 ± 1.0	9.1 ± 0.5
S	Male	25	11.6 ± 1.3	12.6 ± 0.5
	Female	35	10.2 ± 1.2	10.1 ± 0.6
MP_{3cap}	Male	54	13.2 ± 1.2	13.8 ± 0.7
	Female	76	11.4 ± 1.3	12.1 ± 0.9
DP_{3u}	Male	8	14.3 ± 0.8	15.9 ± 0.2
	Female	31	12.6 ± 1.4	13.9 ± 0.4
MP_{3u}	Male	15	15.4 ± 1.7	17.5 ± 0.7
	Female	61	14.1 ± 1.5	15.7 ± 0.7

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 2. The association ranged from 0.47 to 0.66 for male subjects and from 0.31 to 0.69 for female subjects. The tooth

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TABLE 2. Correlation Coefficients Between Skeletal and Dental Development Stages in Male and Female Subjects

Tooth	Correlation Coefficient†	
	Female Subjects	Male Subjects
Canine	0.65*	0.56*
First premolar	0.65*	0.64*
Second premolar	0.69*	0.66*
Second molar	0.68*	0.63*
Third molar	0.31*	0.47*

† Values are *r* values.
* Correlation is significant at the .01 level.

sequence in order of the highest to the lowest correlation for male subjects was the second premolar, the first premolar, the second molar, the canine, and the third molar; the corresponding sequence in female subjects was the second premolar, the second molar, the first premolar as well as the canine, and the third molar. The second premolar was the tooth showing the highest correlation as indicated by r value of 0.66 and 0.69 ($P < .01$) for male and female subjects, respectively. The third molar showed the lowest correlation for both sexes. ($r = 0.47$ in male subjects, $r = 0.31$ in female subjects, $P < .01$ for each). For female subjects, almost all of the teeth studied, except for the third molar, showed virtually the same correlation. The correlation coefficients of the first and second premolars, as well as the second molar, were somewhat similar in male subjects.

Percent distributions for the relationship between the stages of calcification of individual teeth and the stages of skeletal maturity are shown in Tables 3 through 7. The third molar was excluded from the determination because of its poor association with skeletal maturity.

At the MP_3 stage (Table 3), the canine stage F and the second premolar stage E in female subjects showed the highest percent distribution (63.2%), whereas all of the remaining teeth had a scattered distribution. For male sub-

TABLE 3. Percent Distribution of Calcification Stages of Individual Teeth at the MP_3 Stage

Stage	Canine		First Premolar		Second Premolar		Second Molar	
	Female	Male	Female	Male	Female	Male	Female	Male
D							26.3	16.2
E	15.8	5.4	47.4	16.2	63.2	27	52.6	32.4
F	63.2	54.1	36.8	45.9	26.3	48.6	10.5	24.3
G	15.8	18.9	0	21.6	10.5	16.2	10.5	27
H	5.3	18.9	5.3	16.2	0	8.1	0	3
Missing	0	2.7	10.5	0	0	0	0	0
Total*	100.1	100	99.9	100	100	99.9	99.9	99.9

* Because of rounding, values may not total 100.

TABLE 4. Percent Distribution of Calcification Stages of Individual Teeth at the S Stage

Stage	Canine		First Premolar		Second Premolar		Second Molar	
	Female	Male	Female	Male	Female	Male	Female	Male
D			2.9	0	5.7	0	11.4	0
E	5.7	4.0	28.6	8.0	22.9	8.0	51.4	20.0
F	45.7	32.0	40.0	16.0	54.3	36.0	22.9	28.0
G	31.4	28.0	20.0	48.0	11.4	44.0	14.3	40.0
H	17.1	28.0	8.6	24.0	5.7	12.0	0	12.0
Missing	0	8.0	0	4.0	0	0	0	0
Total*	99.9	100	100.1	100	100	100	100	100

* Because of rounding, values may not total 100.

TABLE 5. Percent Distribution of Calcification Stages of Individual Teeth at the MP_{3cap} Stage

Stage	Canine		First Premolar		Second Premolar		Second Molar	
	Female	Male	Female	Male	Female	Male	Female	Male
E	1.3	0	11.8	0	18.4	0	30.3	1.9
F	27.6	5.6	26.3	9.3	34.2	13.0	21.1	11.1
G	22.4	14.8	30.3	9.3	28.9	44.4	39.5	66.7
H	48.7	77.8	31.6	81.5	18.4	42.6	9.2	20.4
Missing	0	1.9	0	0	0	0	0	0
Total*	100	100.1	100	100.1	99.9	100	100.1	100.1

* Because of rounding, values may not total 100.

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TABLE 6. Percent Distribution of Calcification Stages of Individual Teeth at the DP_{3u} Stage

	Canine		First Premolar		Second Premolar		Second Molar	
Stage	Female	Male	Female	Male	Female	Male	Female	Male
E							6.5	0
F	6.5	0	9.7	0	22.6	0	22.6	0
G	12.9	12.5	25.8	0	45.2	12.5	54.8	37.5
H	71.0	87.5	64.5	100.0	32.3	87.5	12.9	62.5
Missing	9.7	0	0	0	0	0	3.2	0
Total*	100.1	100	100	100	100.1	100	100	100

* Because of rounding, values may not total 100.

TABLE 7. Percent Distribution of Calcification Stages of Individual Teeth at the MP_{3u} Stage

	Canine		First Premolar		Second Premolar		Second Molar	
Stage	Female	Male	Female	Male	Female	Male	Female	Male
E					1.6	0	1.6	0
F			1.6	0	1.6	0	0	0
G	4.9	6.7	4.9	6.7	16.4	20.0	52.5	40.0
H	93.4	93.3	93.4	93.3	80.3	73.3	45.9	53.3
Missing	1.6	0	0	0	0	6.7	0	6.7
Total*	99.9	100	99.9	100	99.9	100	100	100

* Because of rounding, values may not total 100.

jects, the canine stage F also presented the highest distribution (54.1%) among all of the teeth studied.

At the S stage (Table 4), in female subjects, the second premolar stage F and the second molar stage E demonstrated marked distinction of the percent distribution (54.3% and 51.4%, respectively), whereas in male subjects, no tooth calcification stages in any teeth studied had a distribution greater than 50%.

At the MP_{3cap} stage (Table 5), wide distribution of tooth calcification stages was clearly seen in all of the teeth for female subjects, with less than 50% in each stage. For male subjects, root formation of the canine as well as the first premolar was completed (stage H) in the majority of the subjects (77.8% and 81.5%, respectively), and the second molar development was highly concentrated in stage G (66.7%). There were no predominant calcification stages for the second premolar ($<$ 45% in each stage).

At the DP_{3u} stage (Table 6), in female subjects, most of the canine and first premolars were in stage H (71% and 64.5%, respectively). In male subjects, the root formation of most of the teeth, with the exception of the second molar, has attained stage H.

At the MP_{3u} stage (Table 7), in both sexes, most of the tooth formation of all of the teeth, with the exception of the second molar, showed stage H calcification. The second molar development was approximately equally distributed between stages G and H.

Reproducibility of assessments

The reproducibility of all of the assessments was found to be good, with high coefficient values. The coefficients of reliability were 0.99 for the skeletal age and dental calcification stage assessments and 1.00 for the skeletal maturity assessment.

DISCUSSION

Dental maturity assessment

Panoramic radiographs were used to assess dental maturity because they are routinely available in orthodontic clinics, and the mandibular region is clearly visible.

There are a number of standard scales for rating the tooth calcification stage.[17,25–27] The method described by Demirjian et al[21] was chosen in the present study because its criteria consist of distinct details based on shape criteria and proportion of root length, using the relative value to crown height rather than on absolute length. Foreshortened or elongated projections of developing teeth will not affect the reliability of assessment.

Skeletal age assessment

The skeletal age for each hand-wrist radiograph was assigned according to the method outlined in the atlas of Greulich and Pyle,[24] which is quick and relatively easy to learn and perform. Because it is less time consuming in practice than the bone stage and weighting system of Tanner et al and shows greater reproducibility between observers,[28,29] the Greulich and Pyle method seems to be highly practical for clinical use in skeletal age assessment.

It is, however, essential to bear in mind the differences between the local population and the reference population used to define the standards in the atlas. Thus, the given

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TABLE 8. Comparisons of Mean Chronological Ages in Years

Stage	Grave and Brown[33] Female	Grave and Brown[33] Male	Fishman[4] Female	Fishman[4] Male	Present Study Female	Present Study Male
MP_3	9.7	11.2	10.6	11.7	9.7	11.2
S	11.3	13.5	11.2	12.3	10.2	11.6
MP_{3cap}	12.4	14.0	12.1	13.8	11.4	13.2
DP_{3u}	13.1	15.4	13.1	15.1	12.6	14.3
MP_{3u}	14.3	16.0	14.8	16.4	14.1	15.4

skeletal age values or standard plates might differ and should be recalibrated for each local population.

By the time the skeletal age assessment was performed, hand-wrist radiographs from male subjects clearly differed from the standard plates more frequently than those of the female subjects, particularly in the carpal bone area, which always showed less maturity compared with the other bones. This observation corresponded with the findings of Acheson et al[28] and Carpenter and Lester,[30] who found that the maturity of the carpal bones varies greatly and influences skeletal age assessment. Carpenter and Lester suggested that when reading the skeletal age by comparing the hand-wrist radiographs with the Greulich and Pyle atlas, clinicians should be careful to examine the entire radiograph and should place less emphasis on the carpal bones. As a result, during the skeletal age assessment in this study, the examiners also paid more attention to the entire radiograph.

Skeletal maturity assessment

In this study, the skeletal maturity assessment was based on the system of Fishman.[4] This technique 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.[4] It is also an advantage to exclude the carpals from the system since irregularity in the order of onset of ossification occurs more frequently in the carpals than in the metacarpal or phalangeal epiphyses.[24]

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 used in the system were selected in the present study.

As illustrated by Fishman,[31] meaningful interpretation of growth status was represented by these skeletal maturity stages. The MP_3 stage appears during the onset of accelerating growth velocity. The S and the MP_{3cap} stages become visible during a period of very rapid growth velocity. The DP_{3u} and MP_{3u} stages coincide with the time interval of decelerating growth rate.

The mean age for each skeletal maturity level presented in Table 1 indicated that female subjects mature earlier than male subjects by an average of 1.5 years. This finding confirms the basic information contained in several reports.[4,32–34] Although the average ages for the 5 skeletal maturity stages were within the range of those derived from other population groups as listed in Table 8, Thai children and adolescents seemed to be a little more advanced in chronological age in agreement with the previous report by Mathurasai and Viteporn.[35]

Differences between skeletal age and chronological age for each of the skeletal maturity stages were noted for both sexes (Table 1). As a whole, the present study group showed little variation in skeletal development. The first 3 stages, MP_3, S, and MP_{3cap}, demonstrated smaller deviations between skeletal and chronological ages than did the DP_{3u} and the MP_{3u} stages. Cole and coworkers[29] have explained that there are 3 sources for the discrepancy between skeletal age and chronological age: natural variations between individuals in their rates of skeletal maturation, systematic error inherent in the method used to assess skeletal age, and variation between different observers.

In this study, it is possible that the first 2 sources influenced the discrepancy between skeletal and chronological ages. Observation error was probably least likely, since skeletal age assessment was performed by 3 examiners simultaneously, and the reproducibility test showed a very strong coefficient of reliability ($r = 0.99$) between double assessments.

The natural variation in skeletal maturation rate between the subjects whose radiographs were used to set the standard plates in the atlas and the subjects in this study may in part be associated with environmental factors and racial differences.

Systematic error of the atlas method might be derived from widely spaced standards. Some hand-wrist radiographs of the sample were not exactly comparable to the standard plates.

Dental and skeletal maturity

From the present findings, maturation patterns of tooth development have shown that male individuals tend to be more advanced as compared with female individuals in relation to skeletal maturity stages. At the same skeletal maturity stage, male subjects had a higher distribution toward late dental developmental stages, whereas the opposite pattern was present in female subjects, as clearly seen in the bar graph illustration. This result was similar to that obtained by Chertkow,[36] who studied the relationship between early presence of ulnar sesamoid and tooth mineralization in 66 white and 22 black boys and 93 white and 16 black girls in South Africa and reported that a markedly more advanced trend in tooth calcification was evident among the boys. It is suggested that tooth mineralization relative to stages of skeletal maturation be considered individually for male and female individuals.

The correlation coefficients between skeletal maturity

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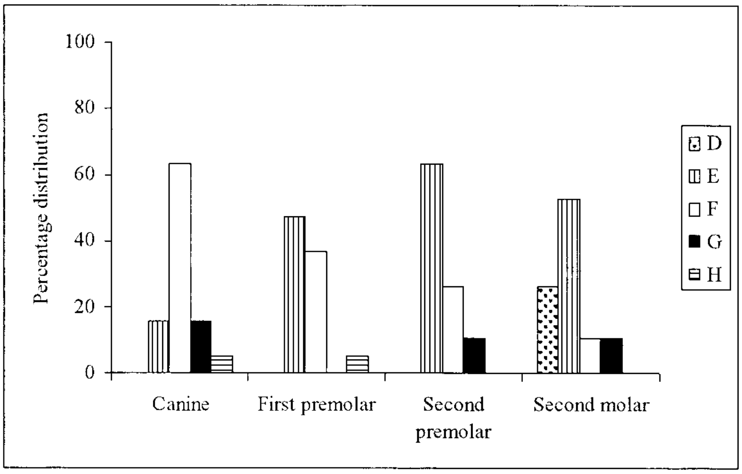

FIGURE 2. Percent distribution of stages of calcification of various teeth at the MP_3 stage in female subjects.

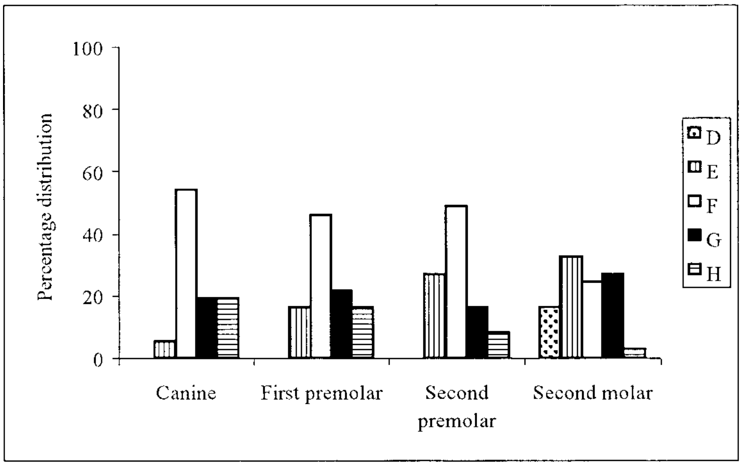

FIGURE 3. Percent distribution of stages of calcification of various teeth at the MP_3 stage in male subjects.

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and calcification stages of the teeth, with the exception of the third molar, were quite high, ranging from 0.56 to 0.69, and were statistically significant ($P < .01$).

For both sexes, a weak correlation was found between the lower third molar development and skeletal maturity ($r = 0.31$ for female subjects, $r = 0.47$ for male subjects). This finding agreed with those of Garn et al,[37] who reported a poor relationship between third molar formation and skeletal maturity. Great variation in development of this tooth, as stated by many investigators,[38,39] may adversely affect the identification of the relationship between dental and skeletal development. However, in contrast to the finding in the present study, Ëngstrom and coworkers[40] found a strong correlation ($r = 0.72$). The strong relationship reported may have resulted from the use of fewer differentiated stages of mandibular molar development in their study. This tooth offers an advantage over other teeth because its development tends to continue over a longer period and until a later age; however, in light of the weak correlation found in this study, we do not recommend use of the stage of third molar formation for comparison with skeletal maturity.

Chertkow,[36] Chertkow and Fatti,[41] Sierra,[42] and Coutinho et al[43] have suggested a high relationship between calcification of mandibular canine and skeletal maturity indicators. The present study found a similar trend, with an r value of 0.56 for male subjects and 0.65 for female subjects. Chertkow and Fatti and Chertkow also reported that mandibular canine stage G coincided with the early appearance of the sesamoid in 77% of their sample and in boys as well as in girls. In this study, no uniformity in canine development was found relative to the S stage. This is in accordance with the study by So,[44] who found no close relation between early ossification of the sesamoid and complete root formation with open apex of the mandibular canine calcification stage.

It is interesting to note that in the present study, strong correlations were found in the premolars and the second molars.

Considering a group of teeth segregated according to

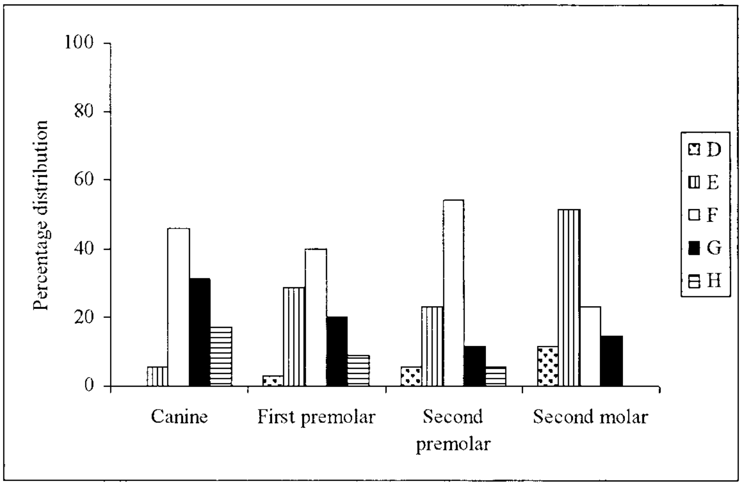

FIGURE 4. Percent distribution of stages of calcification of various teeth at the S stage in female subjects.

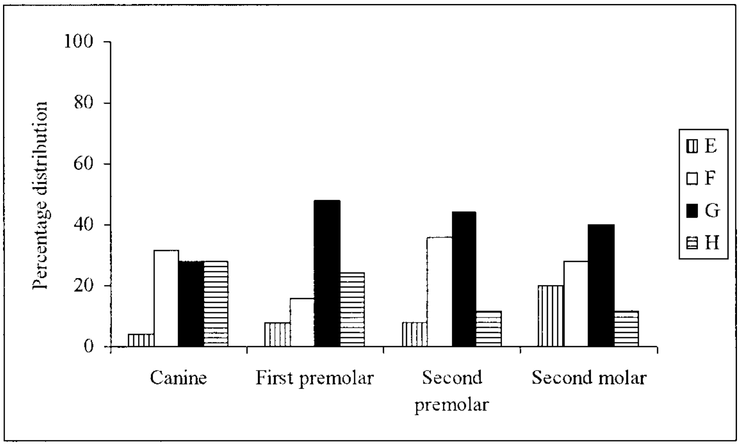

FIGURE 5. Percent distribution of stages of calcification of various teeth at the S stage in male subjects.

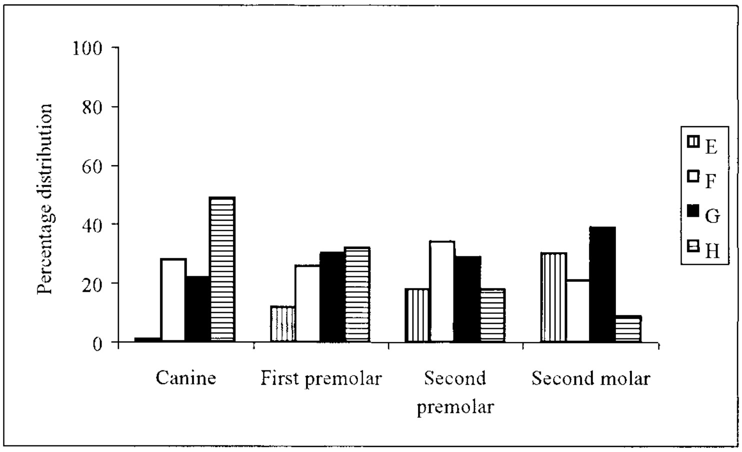

FIGURE 6. Percent distribution of stages of calcification of various teeth at the MP_{3cap} stage in female subjects.

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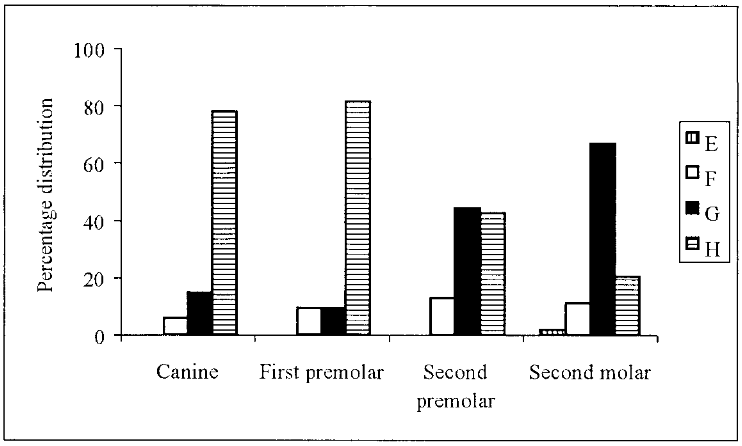

FIGURE 7. Percent distribution of stages of calcification of various teeth at the MP_{3cap} stage in male subjects.

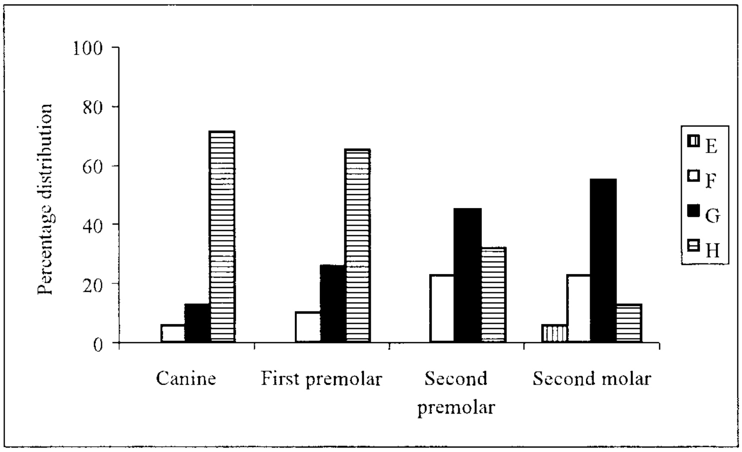

FIGURE 8. Percent distribution of stages of calcification of various teeth at the DP_{3u} stage in female subjects.

subjects' sex, some trends of dental development in relation to skeletal maturity were noticeable. (Figures 2 through 11) At the MP_3 stage, the majority of the canine in both sexes attained root formation in stage F. For female subjects, the second premolar stage F and the second molar stage E showed a high percentage distribution at the S stage. For male subjects, the second molar stage G markedly commenced at the MP_{3cap} stage.

A large number of the canines and first premolars had already attained apical closure since the MP_{3cap} stage for male subjects and the DP_{3u} stage onward for female subjects. Therefore, the interpretation of the relationship between the stage of dental and skeletal development from these teeth and the late stages of skeletal maturity was not meaningful.

The various associations reported in previous investigations and the results found in the present study may possibly be explained by different methods and approaches in data collection as well as by racial variations. An additional explanation may be that the present sample in some skeletal developmental levels was relatively small in size. The percent distribution of the dental developmental stages was largely affected by only a small change in the number of the sample. Enlarging the sample size might ensure more valid information.

Clinical implications

Many investigators have studied the optimal time for treating patients with orthopedic appliances. McNamara et al[45] reported that in children treated with the Fränkel appliance, a larger increase of mandibular length was evidenced at ages estimated to be closer to puberty than at younger ages. Pancherz and Hägg[46] and Hägg and Pancherz[47] related the effect of treatment with the Herbst appliance to longitudinal records of standing height and concluded that the skeletal effect of the appliance was more pronounced during the peak height velocity period than during the prepeak period. A similar appropriate treatment time was also suggested by Malmgren et al,[48] who investigated the skeletal effect of a modified activator combined with high-pull headgear. Kopecky et al[3] showed that the

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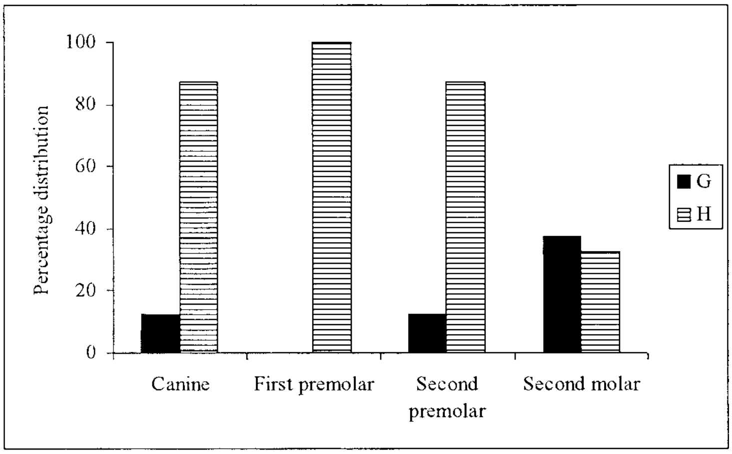

FIGURE 9. Percentage distribution of stages of calcification of various teeth at the DP_{3u} stage in male subjects.

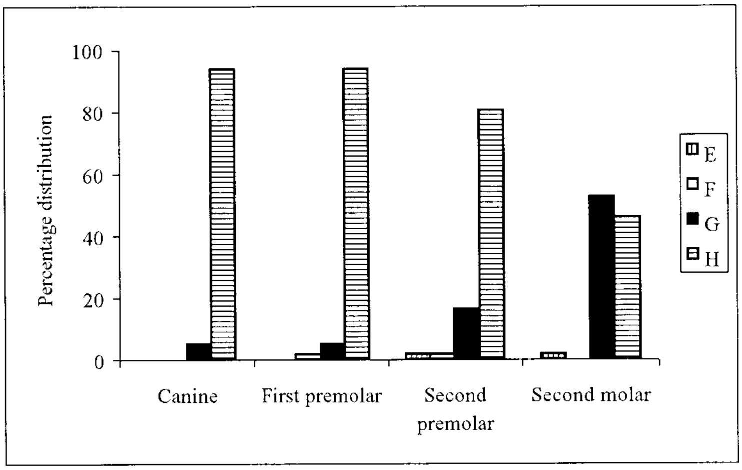

FIGURE 10. Percentage distribution of stages of calcification of various teeth at the MP_{3u} stage in female subjects.

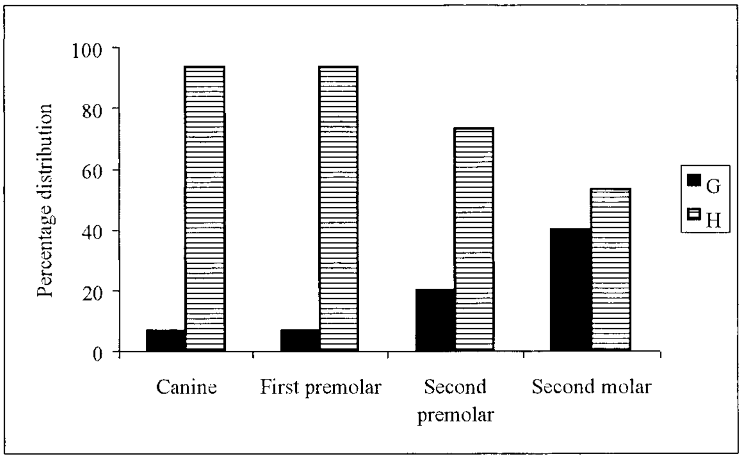

FIGURE 11. Percentage distribution of stages of calcification of various teeth at the MP_{3u} stage in male subjects.

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skeletal correction with cervical-pull headgear could be initiated during the accelerating growth period and continued through the peak velocity period, depending on the severity of skeletal malrelationship.

According to the skeletal maturity stages assessed from hand-wrist radiographs that can represent pubertal growth indicators, orthodontists who expect more orthopedic effect should consider starting treatment during the MP_3 stage, the S stage (in female patients), and the MP_{3cap} stage (in male patients). Treatment rendered after these stages may result in more dental rather than skeletal effects.

From the present study, the relationship between the tooth calcification stages and the skeletal maturity indicators probably allows the clinician to more easily identify the stages of the pubertal growth period from the panoramic radiographs. We found that the canine stage F may represent the MP_3 stage and could serve as a simple tool for evaluating the onset of the accelerating growth period. The second molar stage E for female subjects, coinciding with the S stage, and the second molar stage G for male subjects, coinciding with the MP_{3cap} stage, were indicative of a very high rate of growth acceleration.

CONCLUSION

The relationship between the stages of calcification of various teeth and skeletal maturity stages was evaluated from dental panoramic and hand-wrist radiographs of 139 male subjects and 222 female subjects ranging in age from 7 years to 19 years.

From the correlation coefficients and the percent distribution of stages, there was a relationship between dental and skeletal development; however, the relationship differed for individual teeth. At the same skeletal maturity stage, the dental maturational patterns of male subjects were ahead of those of female subjects.

The canine stage F for both sexes coincided with the MP_3 stage and indicated the onset of a period of accelerating growth. The second molar stage E for female subjects and stage G for male subjects were related to the S stage and MP_{3cap} stage, respectively, and were indicative of the period of very rapid growth velocity.

The findings of this study indicate that tooth calcification stages might be clinically used as a maturity indicator of the pubertal growth period. However, further study is recommended in a larger sample size, and future studies should address development of the canines and second molars.

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