

Correlation of calcification of permanent mandibular canine, mandibular premolars, and permanent mandibular first and second molars with skeletal maturity in Indian population

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Abstract

Context: Morphological variation in children can be understood by the knowledge of growth and development. The state of dental development can be used in forensic odontology to ascertain the age of an unidentified child. **Aims:** This study aims to investigate the relationship of the stages of calcification of the permanent mandibular canine, mandibular premolars, and permanent mandibular first and second molars with skeletal maturity using panoramic and hand–wrist radiographs. **Settings and Design:** This descriptive work was designed as a cross-sectional study. **Materials and Methods:** The study was conducted on 300 healthy subjects (150 males and 150 females) ranging 7–20 years of age. Demirjian's method and Björk, Grave, and Brown's method were used to correlate teeth calcification and skeletal maturity, respectively. **Statistical Analysis Used:** Descriptive statistics and Spearman's rank correlation coefficient were used. **Results:** 1. Correlation coefficients between the skeletal maturity stages and the developmental stages of the five teeth ranged 0.461–0.877 for females and 0.480–0.790 for males. 2. The second molar showed the highest and the first molar showed the lowest relationship for female and male subjects in the Indian population. **Conclusions:** The findings of this study indicate that tooth calcification stages might be clinically used as a maturity indicator of the pubertal growth period.

Key words: Forensic odontology, skeletal maturity, teeth calcification


Introduction

Bone age and skeletal development are as important as chronological age in determining an individual's physical development. Skeletal age also allows the

prediction of final height of a growing individual. The somatic maturity stage can be assessed by hand–wrist radiographs.

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The stages of tooth eruption and the stages of tooth formation can be utilized for determination of dental maturity. The periapical or panoramic radiographs can be used to assess physiologic maturity without resorting to hand-wrist radiographs.

Some studies have shown that the correlations between tooth mineralization and other parameters of physical development are generally low, whereas there is little more than slight covariation between tooth eruption and the adolescent growth spurt. Racial variations in the relationship have also been suggested. The predominant ethnic origin of the population, climate, nutrition, socioeconomic levels, and urbanization are causative factors of this racial variation.^[1] The dental system is an integral part of the human body; its growth and development can and should be studied in parallel with other indicators of physiological maturity, such as bone age, menarche, and height.^[2]

At the start of this study, we thought that Indian children might have a rhythm of skeletal and dental maturation during pubertal development that is different from that of children from the 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 subjects.

Materials and Methods

The study was conducted on 300 healthy Indian subjects. The age of the subjects ranged 7–20 years. Out of these 300 subjects, 150 were males and 150 were females. Patients with congenital anomaly, developmental/systemic disorders, nutritional deficiencies, and prolonged illness were excluded from the study.

Every included subject underwent exposure for panoramic radiograph (Planmeca Proline CC panoramic x-ray, Planmeca OY, Helsinki, Finland). Parameters used were 60–80 kV ± 2.5 kV (constant 68–70 kV), 4–12 mA ± 1.0 mA (constant 10 mA), constant exposure time of 18 s, and constant magnification of 1.2, and all subjects also underwent exposure for hand-wrist radiographs (Vision Extraoral x-ray machine A-100, made in Mumbai, India). Parameters used were 40–100 kV (constant 40–42 kV), 25–100 mA (constant 25 mA), 002–600 mAs (constant 002–003 mAs).

Tooth calcification was rated according to the method described by Demirjian *et al.*^[1,3] in which one of eight stages of calcification, A to H, was assigned for the permanent mandibular canine, premolars, and permanent first and second molars of the right side [Table 1]. Skeletal maturation of each hand-wrist radiograph was determined according

Table 1: Tooth calcification in eight stages of calcification, A to H, according to the method described by Demirjian *et al.*

| Stages of calcification | Description | Diagrammatic representation for single rooted and multirooted teeth |
|-------------------------|---|---|
| Stage A | Calcification of single occlusal points without fusion of different calcifications | |
| Stage B | Fusion of mineralization points; the contour of the occlusal surface is recognizable | |
| Stage C | Enamel formation has been completed at the occlusal surface and dentine formation has commenced. The pulp chamber is curved | |
| Stage D | Crown formation has been completed to the level of the amelocemental 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 commenced 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 the roots a distinct form | |
| Stage G | The walls of the root canal are now parallel, but the apical end is partially open. In molars, only the distal root is rated | |
| Stage H | The root apex is completely closed (distal root in molars). The periodontal membrane surrounding the root and apex is uniform in width throughout | |

to the method described by Björk, Grave, and Brown,^[1,4,5] and respective scores were given to each subject from 1 to 9 [Table 2].

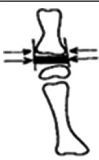
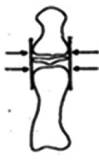







The date of birth obtained from each subject was converted into the age of the subject in completed years and months. This was termed as the chronological age of the subject.

The chronological age of a subject is calculated by subtracting the birth date from the date on which the radiograph was exposed for that particular subject.

Results

The distribution of chronological ages for all the subjects, grouped by skeletal maturity indicators, is shown in Table 3.

Table 2: Skeletal maturation of each hand-wrist radiograph according to the method described by Björk, Grave, and Brown

| Stages of skeletal maturity | Description | Diagrammatic representation |
|--|--|---|
| Stage 1 (PP2) | The epiphysis of the proximal phalanx of the index finger (PP2) has the same width as the diaphysis |  |
| Stage 2 (MP3) | The epiphysis of the middle phalanx of the middle finger (MP3) is of the same width as the diaphysis |  |
| Stage 3 (Pisi-H1-R) | Pisi, visible ossification of the pisiform. H1, ossification of the hamular process of the hamatum. R, same width of epiphysis and diaphysis of the radius |  |
| Stage 4 (S-H2) | S, first mineralization of the ulnar sesamoid bone of the metacarpophalangeal joint of the hamatum. H2, progressive ossification of the hamular process of the hamatum |  |
| Stage 5 (MP3 _{cap} -PP1 _{cap} -R _{cap}) | During this stage, the diaphysis is covered by the cap-shaped epiphysis. In the MP3 _{cap} , the process begins at the middle phalanx of the third finger, in the PP1 _{cap} at the proximal phalanx of the thumb, and in the R _{cap} at the radius |  |
| Stage 6 (DP3 _u) | Visible union of epiphysis and diaphysis at the distal phalanx of the middle finger (DP3) |  |
| Stage 7 (PP3 _u) | Visible union of epiphysis and diaphysis at the proximal phalanx of the little finger (PP3) |  |
| Stage 8 (MP3 _u) | Union of epiphysis and diaphysis at the middle phalanx of the middle finger is clearly visible (MP3) |  |
| Stage 9 (Ru) | Complete union of epiphysis and diaphysis of the radius |  |

The mean ages for each stage of skeletal maturity were consistently younger in female subjects. The appearance of each stage was consistently earlier in female subjects than in the male subjects.

All the correlations between skeletal and dental stages were statistically highly significant at the $P < 0.0001$ significance level [Table 4].

The second molar showed the highest correlation, as indicated by a P value of 0.877 and 0.790 ($P < 0.0001$) for female and male subjects, respectively. The first molar showed the lowest correlation for both sexes ($P = 0.461$ for female subjects, and $P = 0.480$ for male subjects). The correlation coefficients of the canine and second premolars were somewhat close in male subjects.

Table 3: Distribution of chronological ages for all subjects grouped by skeletal maturity indicators

| Maturation stage | Sex | No. of subjects | Chronological age |
|--|--------|-----------------|-------------------|
| | | | Mean ± SD (years) |
| PP2 | Male | 53 | 8.09 ± 1.45 |
| | Female | 09 | 7.06 ± 0.50 |
| MP3 | Male | 34 | 11.10 ± 0.96 |
| | Female | 10 | 8.10 ± 0.29 |
| Pisi-H1-R | Male | 10 | 12.09 ± 0.40 |
| | Female | 16 | 10.01 ± 0.56 |
| S-H2 | Male | 16 | 12.10 ± 0.34 |
| | Female | 19 | 11.11 ± 0.50 |
| MP3 _{cap} -PP1 _{cap} -R _{cap} | Male | 04 | 14.08 ± 1.68 |
| | Female | 23 | 12.01 ± 0.74 |
| DP3 _u | Male | 02 | 15.01 ± 0.00 |
| | Female | 07 | 12.08 ± 0.74 |
| PP3 _u | Male | 01 | 15.03 ± 0.00 |
| | Female | 01 | 13.03 ± 0.00 |
| MP3 _u | Male | 10 | 15.02 ± 1.04 |
| | Female | 19 | 13.10 ± 0.88 |
| R _u | Male | 20 | 17.07 ± 0.76 |
| | Female | 46 | 17.02 ± 1.30 |
| Total | | 300 | 12.07 ± 3.28 |

Table 4: Correlation coefficients between skeletal and dental maturity stages of subjects

| Tooth | Correlation coefficients | | | |
|-----------------|--------------------------|------------------------|---------------|------------------------|
| | Female subjects | | Male subjects | |
| | P | Significance | P | Significance |
| Canine | 0.808 | 0.000 HS, $P < 0.0001$ | 0.768 | 0.000 HS, $P < 0.0001$ |
| First premolar | 0.851 | 0.000 HS, $P < 0.0001$ | 0.741 | 0.000 HS, $P < 0.0001$ |
| Second premolar | 0.865 | 0.000 HS, $P < 0.0001$ | 0.760 | 0.000 HS, $P < 0.0001$ |
| First molar | 0.461 | 0.000 HS, $P < 0.0001$ | 0.480 | 0.000 HS, $P < 0.0001$ |
| Second molar | 0.877 | 0.000 HS, $P < 0.0001$ | 0.790 | 0.000 HS, $P < 0.0001$ |

P (rho): Correlation coefficients, HS: Highly significant, $P < 0.0001$

At stage 1 (PP2) [Table 5], in female subjects, the canine stage F showed the highest percent distribution (88.9%). For both male and female subjects, the canine Stage F (75.5% for males and 88.9% for females) and for female subjects the first premolar stage E (77.8%) presented the highest distribution.

At stage 2 (MP3) [Table 6], wide distribution of tooth calcification stages was seen in all the teeth for male and female subjects. For male and female subjects, the first molar stage H demonstrated the highest distribution (85.3% and 70.0%, respectively). In female subjects, except in the first molar, no other teeth attained the stage H of complete mineralization. Sixty percent of females presented with stage F in canine and first premolar, stage E in second premolar, and stage D in second molar.

Wide distribution of tooth calcification stages was seen clearly in all the teeth for both male and female subjects, **at stage 3 (Pisi-H1-R)** [Table 7]. In male subjects, the canine stages G (60%), the first premolar stage G (50%) and F (50%), the first molar stage H (100%), and the second molar stage H (60%) demonstrated marked distinction of the percent distribution. In female subjects, canine stages G (50%), first premolar stage F (62.5%), second premolar stage F (75%), first molar stage H (87.5%), and second molar stage E (50%) demonstrated marked distinction.

At stage 4 (S-H2) [Table 8], in both sexes, the first molar stage H showed the highest percent distribution, that is, 100% in males and 84.2% in females. In females, canine stage G (68.4%), first premolar stage G (68.4%), and second premolar stage G (52.6%) showed high percent distribution. In males, canine stage H (50%), first premolar stage H (68.8%), second premolar stage G (62.5%), and second molar stage G (75%) showed high percent distribution.

Root formation, that, is stage H of the canine, first premolar, second premolar, and first molar was completed in the male subjects (100%) **at stage 5 (MP3_{cap}, PP1_{cap}, R_{cap})** [Table 9]. The development of the second molar became highly dense in stage H (75%) for males and in stage G (95.7%) for females, and the development of the second premolar became highly dense in stage G (73.9%) for females.

At stage 6 (DP3u) [Table 10], Root formation of the canine in male subjects and root formation of first molar in male and female subjects was completed (100%). In male subjects, the first premolar stage G, second premolar stage G, and second molar stage F showed 100% distribution, while in female subjects 100% distribution was seen in only the second molar G stage. The development of the first premolar was highly concentrated in stage G for females (71.4%). In males, complete root formation was not yet achieved in the first and second premolars, and in the second molar, only stage F had been achieved.

Table 5: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 1 (PP2)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|------|--------|------|-----------------|------|--------|------|-------------|------|--------|------|--------------|------|--------|------|------|------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| C | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 33.3 | 12 | 22.6 |
| D | 1 | 11.1 | 2 | 3.8 | 0 | 0.0 | 4 | 7.5 | 3 | 33.3 | 13 | 24.5 | 0 | 0.0 | 0 | 0.0 | 3 | 33.3 | 27 | 50.9 |
| E | 0 | 0.0 | 5 | 9.4 | 7 | 77.8 | 19 | 35.8 | 5 | 55.6 | 26 | 49.1 | 0 | 0.0 | 0 | 0.0 | 3 | 33.3 | 10 | 18.9 |
| F | 8 | 88.9 | 40 | 75.5 | 2 | 22.2 | 26 | 49.1 | 1 | 11.1 | 10 | 18.9 | 1 | 11.1 | 0 | 0.0 | 0 | 0.0 | 2 | 3.8 |
| G | 0 | 0.0 | 6 | 11.3 | 0 | 0.0 | 4 | 7.5 | 0 | 0.0 | 4 | 7.5 | 6 | 66.7 | 35 | 66.0 | 0 | 0.0 | 2 | 3.8 |
| H | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 22.2 | 18 | 34.0 | 0 | 0.0 | 0 | 0.0 |

Table 6: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 2 (MP3)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|------|--------|------|-----------------|------|--------|------|-------------|------|--------|------|--------------|------|--------|------|------|------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| D | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 6 | 60.0 | 4 | 11.8 |
| E | 0 | 0.0 | 0 | 0.0 | 2 | 20.0 | 0 | 0.0 | 6 | 60.0 | 2 | 5.9 | 0 | 0.0 | 0 | 0.0 | 4 | 40.0 | 12 | 35.3 |
| F | 6 | 60.0 | 12 | 35.3 | 6 | 60.0 | 18 | 52.9 | 4 | 40.0 | 17 | 50.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 6 | 17.6 |
| G | 4 | 40.0 | 19 | 55.9 | 2 | 20.0 | 11 | 32.4 | 0 | 0.0 | 11 | 32.4 | 3 | 30.0 | 5 | 14.7 | 0 | 0.0 | 11 | 32.4 |
| H | 0 | 0.0 | 3 | 8.8 | 0 | 0.0 | 5 | 14.7 | 0 | 0.0 | 4 | 11.8 | 7 | 70.0 | 29 | 85.3 | 0 | 0.0 | 1 | 2.9 |

Table 7: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 3 (Pisi-H1-R)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|------|--------|------|-----------------|------|--------|------|-------------|------|--------|------|--------------|-------|--------|------|------|------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| D | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 6.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 3 | 18.8 | 0 | 0.0 |
| E | 0 | 0.0 | 0 | 0.0 | 1 | 6.3 | 0 | 0.0 | 1 | 6.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 50.0 | 0 | 0.0 |
| F | 6 | 37.5 | 0 | 0.0 | 10 | 62.5 | 0 | 0.0 | 12 | 75.0 | 3 | 30.0 | 0 | 0.0 | 0 | 0.0 | 1 | 6.3 | 3 | 30.0 |
| G | 8 | 50.0 | 6 | 60.0 | 5 | 31.3 | 5 | 50.0 | 2 | 12.5 | 4 | 40.0 | 2 | 12.5 | 0 | 0.0 | 4 | 25.0 | 1 | 10.0 |
| H | 2 | 12.5 | 4 | 40.0 | 0 | 0.0 | 5 | 50.0 | 0 | 0.0 | 3 | 30.0 | 14 | 87.5 | 10 | 100.0 | 0 | 0.0 | 6 | 60.0 |

Table 8: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 4 (S-H2)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|------|--------|------|-----------------|------|--------|------|-------------|------|--------|------|--------------|-------|--------|------|------|------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| E | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 10.5 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 7 | 36.8 | 0 | 0.0 |
| F | 2 | 10.5 | 1 | 6.3 | 3 | 15.8 | 1 | 6.3 | 5 | 26.3 | 1 | 6.3 | 0 | 0.0 | 0 | 0.0 | 3 | 15.8 | 1 | 6.3 |
| G | 13 | 68.4 | 7 | 43.8 | 13 | 68.4 | 4 | 25.0 | 10 | 52.6 | 10 | 62.5 | 3 | 15.8 | 0 | 0.0 | 9 | 47.4 | 12 | 75.0 |
| H | 4 | 21.1 | 8 | 50.0 | 3 | 15.8 | 11 | 68.8 | 2 | 10.5 | 5 | 31.3 | 16 | 84.2 | 16 | 100.0 | 0 | 0.0 | 3 | 18.8 |

Table 9: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 5 (MP3_{cap}-PP1_{cap}-R_{cap})

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|-------|--------|------|-----------------|-------|--------|------|-------------|-------|--------|-------|--------------|-------|--------|------|------|------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| F | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 4.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 4.3 | 0 | 0.0 |
| G | 13 | 56.5 | 0 | 0.0 | 13 | 56.5 | 0 | 0.0 | 17 | 73.9 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 22 | 95.7 | 1 | 25.0 |
| H | 10 | 43.5 | 4 | 100.0 | 10 | 43.5 | 4 | 100.0 | 5 | 21.7 | 4 | 100.0 | 23 | 100.0 | 4 | 100.0 | 0 | 0.0 | 3 | 75.0 |

At stage 7 (PP3u) [Table 11], only one female and one male among all the subjects were found to have skeletal maturity stage 7 (PP3u). In the male subject, root formation was completed in the canine and first molar, while in the female, root formation was completed in the canine, first

premolar, second premolar, first molar, and second molar. In the male, stage G was seen in the first premolar and second premolar, while stage F of calcification was seen in the second molar. In the female subject, calcification stage F and stage G were not seen.

Calcification stages D, E, and F were not seen in stage 8 (MP3_u) [Table 12]. The development of the canine and the first and second premolar teeth was highly concentrated in stage H for females (78.9–94.7%). Root formation of the first molar in all female subjects was completed. The second molar stage G was seen in 42.1% and stage H was seen in 57.9% of female subjects, while 10% of male subjects showed stage G and 90% showed stage H in the second molar.

All the studied teeth in male subjects and the canine, first premolar, second premolar, and first molar in female subjects had completed root formation at stage 9 (R_u) [Table 13]. In female subjects, 4.3% of the second molars showed stage G calcification and 95.7% of second molars showed stage H.

Discussion

Uysal *et al.*,^[1] Krailassiri *et al.*,^[3] and Coutinho *et al.*^[6] reported that the associations 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.

Uysal *et al.*,^[1] Krailassiri *et al.*,^[3] Coutinho *et al.*,^[6] and Chertkow *et al.*^[7] report a high correlation between dental and skeletal ages. On the other hand, Lewis and Garn,^[8] and Garn *et al.*^[9] have reported low or insignificant correlations between the levels of skeletal and dental maturation.

Because the same methods were used, most of the results of the present study are compared with the findings of Uysal *et al.*^[1] and Krailassiri *et al.*^[3] Statistically significant correlations were found between dental calcification stages and skeletal maturity indicators in Indian subjects, similar to Turkish and Thai individuals.

The mean chronological age for each skeletal maturity level as shown in Table 1 indicated that the appearance of each skeletal stage was consistently earlier in the females than in the males, and this finding was in accordance with the information published by Uysal *et al.*,^[1] Krailassiri *et al.*,^[3] Björk *et al.*,^[4] and Grave and Brown.^[5] Uysal *et al.*^[1] reported that the mean chronological age for the Ru stage is earlier in Turkish males than in females, but in the present study it was found that the mean chronological age for each skeletal maturity including Ru stage was consistently earlier in the females.

Table 10: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 6 (DP3_u)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|--------|--------|------|-----------------|--------|--------|------|-------------|--------|--------|-------|--------------|--------|--------|-------|------|-------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| F | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 14.3 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 100.0 |
| G | 4 | 57.1 | 0 | 0.0 | 5 | 71.4 | 2 | 100.00 | 4 | 57.1 | 2 | 100.00 | 0 | 0.0 | 0 | 0.0 | 7 | 100.0 | 0 | 0.0 |
| H | 3 | 42.9 | 2 | 100.00 | 2 | 28.6 | 0 | 0.0 | 2 | 28.6 | 0 | 0.0 | 7 | 100.0 | 2 | 100.00 | 0 | 0.0 | 0 | 0.0 |

Table 11: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 7 (PP3_u)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|-------|----------------|-------|--------|-------|-----------------|-------|--------|-------|-------------|-------|--------|-------|--------------|-------|--------|-------|------|-------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| F | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 100.0 |
| G | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 1 | 100.0 | 0 | 0.0 | 1 | 100.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 |
| H | 1 | 100.0 | 1 | 100.0 | 1 | 100.0 | 0 | 0.0 | 1 | 100.0 | 0 | 0.0 | 1 | 100.0 | 1 | 100.0 | 1 | 100.0 | 0 | 0.0 |

Table 12: Percent distribution (%) of the stages of calcification stages of individual teeth at stage 8 (MP3_u)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|------|----------------|-------|--------|------|-----------------|-------|--------|------|-------------|-------|--------|-------|--------------|-------|--------|------|------|------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| G | 1 | 5.3 | 0 | 0.0 | 1 | 5.3 | 0 | 0.0 | 4 | 21.1 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 8 | 42.1 | 1 | 10.0 |
| H | 18 | 94.7 | 10 | 100.0 | 18 | 94.7 | 10 | 100.0 | 15 | 78.9 | 10 | 100.0 | 19 | 100.0 | 10 | 100.0 | 11 | 57.9 | 9 | 90.0 |

Table 13: Percentage distribution (%) of the stages of calcification stages of individual teeth at stage 9 (R_u)

| Calcification stages | Canine | | First premolar | | | | Second premolar | | | | First molar | | | | Second molar | | | | | |
|----------------------|--------|-------|----------------|-------|--------|-------|-----------------|-------|--------|-------|-------------|-------|--------|-------|--------------|-------|--------|------|------|-------|
| | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | | Female | | Male | |
| | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % | n | % |
| G | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 0 | 0.0 | 2 | 4.3 | 0 | 0.0 |
| H | 46 | 100.0 | 20 | 100.0 | 46 | 100.0 | 20 | 100.0 | 46 | 100.0 | 20 | 100.0 | 46 | 100.0 | 20 | 100.0 | 44 | 95.7 | 20 | 100.0 |

The average ages for the five skeletal maturity stages were within the range of those derived from other population groups, as listed in Table 14.

In the present study, the correlation coefficients indicate that the second molars showed the highest relationship and the first molars showed the lowest correlation for both sexes among Indian subjects. However, in male and female Thai individuals, the second premolar teeth showed the highest correlation coefficients between skeletal and dental development stages.^[3] In the study by Uysal *et al.*^[1] the second molars showed the highest relationship and the third molars showed the lowest correlation for both sexes among Turkish subjects. Because of uncertainty regarding the formation of third molars and poor correlation with skeletal maturity, third molars were excluded from the present study.

In the present study, no uniformity in canine development was found relative to stage S. Uysal *et al.*,^[1] and Krailassiri *et al.*^[3] found a low relationship between early ossification of the sesamoid bone and dental calcification stage G, and in the present study 68.4% of females and 43.8% of males were at canine stage G.

In the present study, root formation of the canine as well as the first premolar was completed in the majority of the subjects at stage 5 (MP3_{cap}, PP1_{cap}, R_{cap}), Stage 6 (DP3_u), and Stage 7 (PP3_u), supporting the suggestions of Uysal *et al.*^[1] and Krailassiri *et al.*^[3]

Many investigators have studied the optimal time for treating patients with orthopedic appliances.^[3] 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 MP3 stage, the S stage (in female patients), and the MP3_{cap} stage (in male patients). Treatment rendered after these stages may result in more dental rather than skeletal effects.^[3] 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. It was found that the canine stage F in females and stage G in males may represent the MP3 stage and could serve as a simple tool for evaluating the onset of the accelerating growth period. The second molar stage G for male subjects, coinciding with the S-H2 stage, and the second molar stage G for female subjects, coinciding with the MP3_{cap}-PP1_{cap}-R_{cap} stage, were indicative of a very high rate of growth acceleration.

Stage A and stage B was not observed in any of the subject studied in the age group of 7–20 years, thus the inclusion of other lower age groups will enable researchers to analyze whether these stages can be correlated with the skeletal maturity stages.

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 using a larger sample size, and future studies should address the development of the canines and second molars.

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Conflicts of interest

There are no conflicts of interest.

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Table 14: Comparisons of mean chronological ages in years

| Stages | Grave and brown ^[5] | | Fishman ^[10] | | Present study | |
|---|--------------------------------|------|-------------------------|------|---------------|-------|
| | Female | Male | Female | Male | Female | Male |
| MP3 | 9.7 | 11.2 | 10.6 | 11.7 | 8.10 | 11.10 |
| S-H2 | 11.3 | 13.5 | 11.2 | 12.3 | 11.11 | 12.10 |
| (MP3 _{cap} -PP1 _{cap} -R _{cap}) | 12.4 | 14.0 | 12.1 | 13.8 | 12.01 | 14.08 |
| DP3u | 13.1 | 15.4 | 13.1 | 15.1 | 12.08 | 15.01 |
| MP3u | 14.3 | 16.0 | 14.8 | 16.4 | 13.10 | 15.02 |