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Comparative Radiographic Evaluation of Relationship between Dental Calcification Stages and Skeletal Maturity Stages of Hand Wrist: An in-Vitro Study

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Introduction

Human growth is complex and influenced by various factors, including hereditary, functional, environmental, sexual, nutritional, and metabolic components. The onset of puberty varies significantly based on sex, generation, population, and environment.[1] A child's developmental status is typically assessed based on milestones occurring throughout growth, with particular importance placed on pubertal growth for managing skeletal deviations. This phase includes an initial, peak, and end period, during which growth accelerates and decelerates at different stages.[2]

Growth modifications are most effective during the adolescent growth spurt, when facial bones develop at an optimal rate.[3] Therefore, orthodontists target this period to correct skeletal malocclusions, as initiating treatment at the ideal stage of skeletal maturation can lead to favorable outcomes with minimal risks.[4] Genetic and hormonal factors play a key role in craniofacial development during puberty, though other factors like health status, nutrition, race, socioeconomic background, and secular trends also contribute. A notable example of secular trends is the declining age of puberty since the 1840s, with menarche occurring earlier—by approximately six months every decade.[5]

Craniofacial growth assessment, especially identifying whether the pubertal growth spurt has started or ended, is essential for accurate diagnosis, treatment goals, planning, and outcomes in orthodontics. It also influences decisions such as the timing of extraoral traction, the use of functional appliances, extraction strategies, and retention protocols.[6] Due to significant variation among individuals of the same chronological age, the concept of physiological or biological age—assessed via somatic, sexual, skeletal, and dental maturity—has been introduced. Skeletal age, morphological age, dental age, and age based on secondary sexual characteristics or menarche have all been proposed for assessing maturity.[7]

Skeletal and dental assessments are common in clinical practice, particularly in orthodontics and dentofacial orthopedics. Skeletal age is considered the most reliable indicator for diagnosis and treatment planning. It is evaluated through visual inspection of ossification changes in growing bones. Various ossification centers—such as those in the hand, wrist, foot, ankle, hip, elbow, and cervical vertebrae—can be examined, with hand-wrist radiographs and lateral cephalograms being the most frequently used methods.[8]

Orthodontists routinely use clinical and radiographic guidelines for assessing skeletal maturation. The concept dates back to Crampton (1903) and was further developed by Todd (1937) and Greulich and Pyle (1959). Björk, Grave, and Brown (1976) categorized hand-wrist development into nine stages, while Fishman (1982) proposed a four-stage bone maturation system using six anatomical sites on the hand and wrist.[9]

Dental maturity, another method for determining biological age, is assessed through tooth eruption or formation, with formation being more reliable. Nolla (1960) proposed ten stages of tooth calcification; Moorrees et al. (1963) created a dentition atlas; and Demirjian et al. (1973)[18] introduced a scoring system with eight stages (A–H). If a strong correlation exists between dental and skeletal maturity, dental calcification stages may serve as an early diagnostic tool for predicting pubertal growth spurts.[10] Assessing mandibular tooth calcification via panoramic radiographs offers a radiation-free alternative to hand-wrist radiographs, aligning with the ALARA (As Low As Reasonably Achievable) principle.[11]

The purpose of this study to evaluate the relations between the dental calcification stages measured on panoramic radiographs and skeletal maturity stages of the hand-wrist region.

Material and Methodology

The data for this study was a retrospective study and data was obtained from patients who visited the Department of Orthodontics and Dentofacial Orthopaedics at in Government Dental College and Hospital, Afzalgunj, Hyderabad. Hand-wrist and panoramic radiographs were collected from 250 participants who were exposed for regular diagnostic purpose and not solely for the study, participants were classified according to gender (male and female) and divided between 9 and 14 years.

The inclusion criteria for the study were: a mean age of 12.5 years (ranging from 9 to 14 years), availability of hand-wrist radiographs, fully erupted incisors and first permanent molars, and good-quality panoramic radiographs. Participants were excluded if they had dental anomalies, a history of premature extraction of primary molars or canines, any trauma or surgical interventions involving the facial structures or hand and wrist, or if they presented with syndromes such as Down syndrome, Pierre Robin syndrome, mandibulofacial dysostosis, amelogenesis imperfecta, ectodermal dysplasia, or Goldenhar syndrome. Additionally, cases with missing mandibular teeth in the left quadrant were excluded from the study.

Material

- 250 Digital OPG radiograph

- 250 Hand wrist radiograph

Methodology

Among the sample of 250 participants aged between 9 and 14 years, the study population was divided into two groups of 125 participants each, with an equal distribution of 125 males and 125 females across the entire sample. Hand-wrist skeletal maturity was evaluated based on the maturation patterns using the classification system of Bjork, Grave, and Brown, which relies on observing specific ossification events in the bones of the hand and wrist. To simplify the assessment and ensure clear differentiation between stages, only five of the nine skeletal maturity stages were used: MP3, R, S, MP3cap, and DP3u. Each of these skeletal maturity stages corresponds to a specific phase of the pubertal growth spurt curve. The growth spurt begins with the MP3 and R stages, followed by a phase of rapid growth velocity during the S and MP3cap stages, and finally transitions into a deceleration phase with the DP3u stage.

For dental maturity assessment, panoramic radiographs were used, specifically focusing on the mandibular left permanent canine, first premolar, second premolar, and second molar. The dental maturity of these teeth was determined by their calcification stages, which were rated according to the Demirjian Index (DI). This index categorizes tooth development into eight stages of calcification, labeled A through H. After evaluating both the hand-wrist skeletal maturity index and the Demirjian index for each subject, a comparative analysis was performed to correlate the stages of dental calcification with the corresponding stages of skeletal maturity.

Figure 1: Panoramic Radiograph (OPG)

Figure 2: Hand wrist radiograph

Results

The present study was conducted to evaluate the relationship between permanent mandibular left canine, first premolar, second premolar and second molar calcification stages and hand wrist skeletal maturation.

A total of 250 participants (125 males and 125 females) of age group between 9 to 14 years were chosen. There are 2 age groups of 125 participants in each group and each age group contains 125 males and 125 females.

Table 1: Distribution of sample in various age groups

Age (Years)	Male	Female	Total Subjects
9	7	6	13
10	15	10	25

11	12	15	27
12	21	23	44
13	41	37	78
14	29	34	63
Total	125	125	250

Table 2 shows the distribution of skeletal maturity stages and gender. In males, the percentage distribution is more in skeletal maturity stage MP3 (27.2%) and R (28.8%). In females, the percentage distribution is more in skeletal maturity stage S (18.4 %), MP3cap (21.6%) and DP3u (33.6%). The Chi square test revealed that the distribution of DI stages in gender is statistically significant. (P value = 0.023).

Table 2: Distribution of sample in skeletal maturity stages and gender

Stages	Males		Females		Chi-square statistic	P value
	n	%	n	%		
MP3	34	27.2	20	16		
R	36	28.8	13	10.4		
S	19	15.2	23	18.4		
MP3cap	22	17.6	27	21.6	3.25	0.023*
DP3u	14	11.2	42	33.6		
Total	125	100%	125	100%		

*P<0.05 is considered as statistically significant

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Table 3: Distribution of stages as in Demirjian index of Canine between the genders

Canine (33)	Males		Females		Chi- square statistic	P value
	n	%	n	%		
E	4	3.2	5	4		
F	24	19.2	18	14.4		
G	55	44	37	29.6	3.56	0.021*
H	42	33.6	65	52		

*P<0.05 is considered as statistically significant

Table 3 shows the distribution of Demirjian index of Canine between the genders. In males, the percentage distribution is more in DI stage F (19.2) and G (44%). In females, the percentage distribution is more in DI stage D (4 %) and H (52%). The Chi square test revealed that the distribution of DI stages in gender is statistically significant. (P value = 0.021).

Table 4: Distribution of stages as in Demirjian index of 1st Premolar between the genders

1st Premolar (34)	Males		Females		Chi- square statistic	P value
	n	%	n	%		
D	2	1.6	1	0.8	1.89	0.22
E	11	8.8	12	9.6		
F	21	16.8	17	13.6		
G	39	31.2	27	21.6		
H	52	41.6	68	54.4		

P<0.05 is considered as statistically significant

Table 4 shows the distribution of Demirjian index of 1st Premolar between the genders. In males, the percentage distribution is more in DI stage D (1.6%), F (16.8) and G (31.2%). In females, the percentage distribution is more in DI stage E (9.6 %) and H (54.4%). The Chi square test revealed that the distribution of DI stages in gender is not statistically significant. (P value = 0.22).

Table 5: Distribution of stages as in Demirjian index of 2nd Premolar between the genders

2nd Premolar (35)	Males		Females		Chi- square statistic	P value
	n	%	n	%		
D	3	2.4	4	3.2	1.35	0.024*
E	17	13.6	14	11.2		
F	17	13.6	15	12		
G	41	32.8	33	26.4		
H	47	37.6	59	47.2		

*P<0.05 is considered as statistically significant

Table 5 shows the distribution of Demirjian index of 2nd Premolar between the genders. In males, the percentage distribution is more in DI stage E (13.2%), F (13.2) and G (32.8%). In females, the percentage distribution is more in DI stage D (3.2 %) and H (47.2%). The Chi square test revealed that the distribution of DI stages in gender is statistically significant. (P value = 0.024).

Table 6: Distribution of stages as in Demirjian index of 2nd Molar between the genders

2nd Molar (37)	Males		Females		Chi- square statistic	P value
	n	%	n	%		
D	6	4.8	7	5.6	2.86	0.040*
E	31	24.8	15	12		
F	31	24.8	23	18.4		
G	56	44.8	52	41.6		
H	11	8.8	28	22.4		

*P<0.05 is considered as statistically significant

Table 6 shows the distribution of Demirjian index of 2nd Molar between the genders. In males, the percentage distribution is more in DI stage E (24.8%), F (24.8) and G (44.8%). In females, the percentage distribution is more in DI stage D (5.6 %) and H (22.4%).The Chi square test revealed that the distribution of DI stages in gender is statistically significant. (P value = 0.040).

Table 7: Correlation coefficients between the skeletal maturity indicators of the hand and wrist bones and the calcification stages of the four teeth for female subjects

Tooth	Bjork stage	MP3		R		S		MP3cap		DP3u	
		n	%	n	%	n	%	n	%	n	%
Canine	E	5	25.0	0	0	0	0	0	0	0	0
	F	12	60.0	4	30.8	2	8.7	0	0	0	0
	G	3	15.0	6	46.2	10	43.5	11	42.3	7	16.3
	H	0	0	3	23.1	11	47.8	15	57.7	36	83.7
1st premolar	D	1	5.0	0	0	0	0	0	0	0	0
	E	11	55.0	0	0	1	4.3	0	0	0	0
	F	6	30.0	5	38.5	4	17.4	2	7.7	0	0
	G	2	10.0	4	30.8	6	26.1	9	34.6	6	14.0
	H	0	0	4	30.8	12	52.2	12	46.2	37	86.0
2nd Premolar	D	4	20.0	0	0	0	0	0	0	0	0
	E	10	50.0	3	23.1	1	4.3	0	0	0	0
	F	4	20.0	2	15.4	5	21.7	4	15.4	0	0
	G	2	10.0	5	38.5	12	52.2	7	26.9	7	16.3
	H	0	0	3	23.1	5	21.7	15	57.7	36	83.7
2nd Molar	D	7	35.0	0	0	0	0	0	0	0	0
	E	10	50.0	2	15.4	1	4.3	1	3.8	0	0
	F	2	10.0	6	46.2	7	30.4	7	26.9	2	4.7
	G	1	5.0	3	23.1	14	**60.9**	15	**57.7**	21	48.8
	H	0	0	2	15.4	1	4.3	6	23.1	20	46.5

Table 7 shows the Spearman rank-order correlation coefficients between the skeletal maturity indicators of the hand and wrist bones and the calcification stages of the four teeth. The correlation was statistically significant and ranged from 0.705 to 0.887 (0.705 to 0.848 in males and 0.782 to 0.887 in females), indicating strong positive correlation. The highest to the lowest correlation was the 2nd molar, the canine, the 1st premolar and the 2nd premolar in males; while, it was the 2nd molar, the 2nd premolar, the 1st premolar, then the canine in females. The 2nd molar showed the highest correlation both in males (r = 0:848, P < 0:001) and females (r = 0:887, P < 0:001). The 2nd premolar showed the lowest correlation (r = 0:705, P < 0:001) in males; while it was canine showed lowest correlation (r = 0:782, P < 0:001) in females.

Table 8: Intra-examiner reliability (Kappa analysis)

Variable	Kappa value	p-value
Skeletal maturation stages (MP3=, R=, S, MP3cap, DP3u)	0.903	.024*
Canine calcification stages	0.955	.012*
1st premolar calcification stages	0.956	.009*
2nd premolar calcification stages	0.944	.021*
2nd molar calcification stages	0.877	.004*

Table 8 depicts Significant (p=0.000) high kappa values shows that the examiner is consistent with his own assessments. Kappa values are 0.903, 0.955, 0.956, 0.944 and 0.877 for Skeletal maturation stages, Canine, 1st premolar, 2nd premolar and 2nd molar calcification stages respectively.

Discussion

Evaluating growth potential and maturation is critical in orthodontics, especially in adolescents with skeletal deviations. Treatment plans, including decisions on extraoral traction, functional appliances, extractions, or orthognathic surgery, often hinge on growth considerations. The AAO recommends initial orthodontic evaluation by age 7 to detect and manage potential issues early, preventing more complex interventions later.[12]

Growth involves cellular organization, differentiation, development, and size increase—all influenced by timing. In orthodontics, the timing of intervention is often more crucial than the chosen treatment protocol.[13]

Various indicators such as height gain, hand-wrist maturation, dental development, menarche or voice changes, cervical vertebral maturation, frontal sinus changes, and biomarkers are used to assess maturity. However, traditional prediction models can overestimate maturity and underestimate growth potential.[14]

Among these, dental maturity offers advantages—it's assessable during routine care and aligns with the ALARA principle by minimizing radiation exposure. Panoramic radiographs are commonly used, avoiding higher-radiation methods like hand-wrist or cephalometric radiographs.[13]

Studies exploring dental and skeletal maturity correlations show mixed results. While some report strong associations, others find weak links, possibly due to methodological differences. Nevertheless, dental development, particularly tooth calcification, is more reliable than eruption timing, which is influenced by external factors.

Tooth mineralization begins with crown formation and ends with root apex closure. Various classification systems, notably Demirjian's A-H staging, assess these stages accurately, especially in Indian populations. Unlike older methods relying on length measurements, Demirjian's system uses shape and proportions, reducing projection errors and inter/intra-examiner variability.[15]

In this study, mandibular canines, premolars, and second molars on the left side were assessed, consistent with Demirjian's original methodology. Second molars were preferred due to their longer developmental span and less susceptibility to anomalies compared to third molars. Maxillary molars were excluded due to overlapping anatomical structures. Skeletal maturation was evaluated using hand-wrist radiographs following Björk, Helm, and Grave & Brown's criteria, focusing on five stages: MP3, R, S, MP3cap, and DP3u. These correspond to specific periods in the pubertal growth spurt. For example, MP3 and R indicate its onset, S and MP3cap mark peak growth, and DP3u signals deceleration.[16]

Dental maturity stages correlated well with skeletal stages. Stage F of the canine and stage E of the second molar coincided with MP3, indicating growth onset. Second premolar stage F aligned with R, and second molar stage G with MP3cap. In males, canine and first premolar roots were often complete by MP3cap; in females, these teeth reached stage H by DP3u.[17]

Girls typically reach skeletal maturity earlier than boys due to higher pre-pubertal estrogen levels. While some studies found no sex difference, others—including those on Telangana populations—confirmed this trend. Differences in findings across studies may be due to ethnicity, age range, diet, and methodology.

Given the strong correlation between dental calcification and skeletal maturity, panoramic radiographs provide a practical alternative to hand-wrist radiographs, especially in resource-limited settings. This approach is effective for assessing growth timing using only the mandibular canine and second molar.[16]

The success of orthopedic and functional therapies depends on their timing within the growth phase. Maxillary interventions like facemask therapy are most effective during early growth spurts, while headgear limits forward maxillary growth. Transverse discrepancies like crossbites can be corrected with RME.[16]

Mandibular growth peaks later; however, early intervention with chincup therapy can manage excessive growth in prognathic mandibles. The pubertal growth spurt is ideal for mandibular growth modification. Functional appliances like the Twin Block, Herbst, or Bionator can stimulate growth in retrognathic mandibles, while chincup therapy can restrain it in prognathism. Proper timing maximizes skeletal and facial corrections.

Conclusion

The present study aimed to evaluate the relationship between the calcification stages of the permanent mandibular canine, first premolar, second premolar, and second molar and skeletal maturity assessed by hand-wrist radiographs, to determine if dental calcification stages could reliably indicate skeletal maturity.[16]

Panoramic (OPG) and hand-wrist radiographs of 250 participants (125 males and 125 females) aged 9–14 years were analyzed. Dental calcification stages were rated using the Demirjian Index (DI), and skeletal maturity was assessed using the Bjork, Grave, and Brown method. Frequency and percentage distributions of dental stages across skeletal maturity stages were calculated by gender. The Chi-square test evaluated the association, and Spearman's rank correlation tested the strength of correlation.[17]

Results showed a highly significant association between hand-wrist skeletal maturity and Demirjian stages in both sexes. Skeletal maturity stages appeared earlier in females. The Canine F stage corresponded to the MP3 stage (pre-pubertal growth spurt) in both sexes.[17] In females, second molar stage G aligned with the S stage; in males, with MP3cap—both indicative of rapid growth phases. Dental mineralization stages provide a simple, practical method for estimating skeletal maturity.

Since panoramic radiographs are routinely used in dental practice, they can serve as an effective initial tool for growth assessment, potentially reducing reliance on hand-wrist radiographs. Thus, dental maturity assessment can aid in timing treatment for skeletal malocclusions, though its clinical utility may have limitations.[18]

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