Original Article

Evaluation of Skeletal Maturation in Indian Adolescents Using Calcification Stages of Permanent Mandibular Second Molar

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Abstract

Aim: The aim of this study was to investigate the relationships between the stages of calcification of teeth (permanent mandibular second molar) and cervical vertebrae maturation (CVM). **Materials and Methods:** This study was conducted on 200 Indian children (98 boys and 102 girls), whose panoramic radiographs (orthopantomogram) for mandibular second molar tooth calcification stages and visual appraisals of the lateral cephalograms for CVM stages, were recorded using Demirjian Index (DI) and CVM indicator (CVMI). **Results:** Each stage appeared earlier in female participants than males. A highly significant association was found between DI and CVMI. Stage F and G of DI, which corresponds to Stage 3 of CVMI indicated the start of the peak in mandibular growth, which would be appropriate time to plan for growth modification appliance placement. Stage G of DI also corresponds to Stage 4 of CVMI, i.e., deceleration of adolescent growth spurt. Stage H of DI corresponding to CVMI Stages 5 and 6 indicates that the peak of mandibular growth has already occurred and is not appropriate for functional appliances. **Conclusion:** Mandibular second molar calcification stages are reliable skeletal maturity indicators for the evaluation of growth phases in children.

Keywords: Calcification, growth prediction, mandibular molar, skeletal maturation

Introduction

Age is one of the essential factors in establishing the identity of a person; however, the rate of growth in any individual shows wide variations and is dependent on the genetic and environmental factors. Assessing maturational status (whether pubertal growth spurt of that child has reached or completed) can have a considerable influence on diagnosis, treatment planning, and the eventual outcome of dental (orthodontic) treatment in children.[1-3] Treatment protocols aimed to enhance or restrain maxillary jaw growth take advantage of treatment performed before the adolescent growth spurt whereas the treatment regimens aimed to enhance or restrain mandibular growth produce greater effects when the pubertal growth spurt is included in the treatment interval.[4]

The relationship between growth and chronological age is not linear. Biological age is the registry of the rate of progress toward maturity that can be estimated by somatic, sexual, skeletal, and dental maturity.[5] Somatic maturity is recognized by the annual growth increments in height or weight.[6] One of the physiologic measures 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.[7-9] The stages of dental calcification could 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.

Garn *et al*.[8] showed only weak correlations between the third molar and skeletal development whereas Engström *et al*.[9] reported stronger relationships. Relationships between

Access this article online	
Quick Response Code:	**Website:** www.ijpedor.org
	DOI: 10.4103/ijpr.ijpr_12_18

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How to cite this article: Chamania S, Patil RU, Prakash A. Evaluation of skeletal maturation in Indian adolescents using calcification stages of permanent mandibular second molar. Int J Pedod Rehabil 2018;3:47-52.

the stages of tooth mineralization of the mandibular canine appear to correlate better with ossification stages than do the other teeth. Racial variations in the relationship have also been suggested. Mappes *et al*.[10] indicated that the predominant ethnic origin of the population, climate, nutrition, socioeconomic levels, and urbanization is causative factors of these racial variations. Relationships between the calcification stages of individual teeth and skeletal maturity have been previously documented.[11,12] The present radiographic study was used to assess the reliability of using the developmental stages of permanent mandibular second molars as an indicator of maturity. This tooth offers an advantage over other teeth because its development tends to continue over a longer period and until a later age. Apex closure generally extends up to the age of 16 years normally. The permanent mandibular second molar was selected as a reference tooth because the calcification stages of this teeth are clearly visible than that of maxillary molars. The maxillary molar roots overlap with anatomic structures such as the palate, inferior border of the zygomatic arch, or the maxillary sinus septum which makes it difficult to observe the roots. The main aim and objective of this study were to investigate the relationship between mandibular second molar calcification stages and cervical vertebrae maturity indicators among the Indian population.

Materials and Methods

A total sample of 200 Indian children (98 boys and 102 girls) of age groups between 9 and 18 years visiting a Dental Institute and Research Centre of central India were included in the study. After taking parents' consent and ethical clearance from the institute, panoramic radiograph (orthopantomogram [OPG]) and lateral cephalogram were taken for each participant and analyzed for growth status.

The inclusion criteria were as follows:
- Chronological age ranging from 9 to 18 years
- Normal overall growth and development without any congenital deformity
- Absence of abnormal dental conditions such as impaction, transposition, and congenitally missing teeth and no permanent teeth extracted
- Absence of a previous history of trauma or disease to the face and neck
- No gross skeletal deformities, for example, clefts, hemiatrophy, hypertrophy, etc.
- Absence of previous orthodontic treatment.

Two parameters used in this study were Demirjian Index (DI) and cervical vertebrae maturation indicator (CVMI) [Figures 1, 2 and Tables 1, 2, respectively]. For dental maturation evaluation, calcification stages of permanent mandibular left second molar were assessed by eight stages of calcification (A to H), assigned to the tooth as per the index described by Demirjian *et al*.[13] The individuals were analyzed by taking panoramic radiograph by using 6” × 12” Kodak film as per the standard procedures. CVM (CVMI analysis) was evaluated by classifying cervical vertebrae C2, C3, and C4 into six stages depending on maturation patterns depicted on the lateral cephalogram using the classification system of Hassel and Farman.[6] For cervical vertebrae (C2, C3, and C4), lateral skull radiographs were be taken on the same machine in 200 clinically healthy children by the same trained operator, by using 8” × 10” Kodak film as per the standard procedure. The film focus distance was 5 feet, and the distance from midsagittal plane to the film was 15 cm.

Results

A highly significant association was found between DI and CVMI. The result of the study showed that each CVMI stage

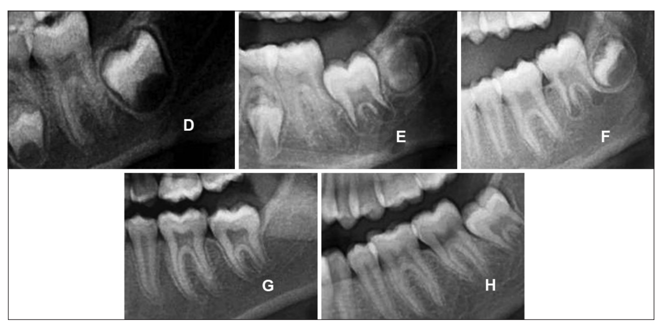

Figure 1: Radiographs of Mandibular second molar showing D to H stages of calcification.

Table 1: Dental calcification stages using the Demirjian Index

Stage	Characteristics
A	Calcification of single occlusal points without fusion of different calcifications
B	Fusion of mineralization points; the contour of the occlusal surface is recognizable
C	Enamel formation has been completed at the occlusal surface, and dentin formation has commenced. The pulp chamber is curved, and no pulp horns are visible
D	The crown formation has been completed to the level of the cementoenamel junction. Root formation has commenced. The pulp horns are beginning to differentiate; however, the walls of the pulp chamber remain curved
E	The root length remains shorter than the crown height. The walls of the pulp chambers are straight, and the pulp horns have become more differentiated than in the previous stage. In molars, the radicular bifurcation has started to calcify
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
G	The walls of the root canal are now parallel; however, the apical end is partially open. In molars, only the distal root is rated
H	The root apex is completely closed (distal root in molars). The periodontal membrane surrounding the root and apex is uniform in width throughout

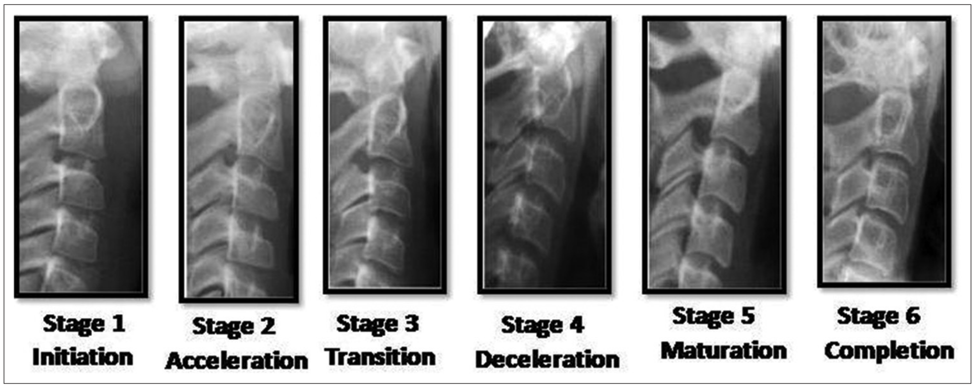

Figure 2: Radiographs of cervical vertebra showing six stages of maturation.

Table 2: Cervical vertebrae maturation indicators (Hassel and Farman)

Stage	Expected growth	Characteristics
1-Initiation	80%-100%	C2, C3, and C4 inferior vertebral body borders are flat. Vertebrae are wedge-shaped. Superior vertebral borders are tapered posterior to anterior
2-Acceleration	65%-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
3-Transition	25%-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
4-Deceleration	10%-25%	Deceleration of adolescent growth spurt. Small amount of adolescent growth expected. Distinct concavities in the inferior borders of C2, C3, and C4. C3 and C4 are nearly square
5-Maturation	5%-10%	Final maturation of the vertebrae takes place during this stage. Insignificant amount of adolescent growth is expected. Accentuated concavities of the inferior vertebral body borders of C2, C3, and C4. C3 and C4 are square
6-Completion	Little or no growth	Adolescent growth is completed. Deep concavities are seen in the inferior borders of C2, C3, and C4. C3 and C4 heights are greater than widths

appears earlier in females than in male participants. CVMI Stage 1 shows the lowest gender difference of 0.5 years whereas CVMI Stage 4 shows higher gender difference of about 1.7 years compared to other stages [Table 3]. The interobserver agreement, the weighted kappa statistics for DI assessments, and CVMI assessments were 0.84 and 0.87, respectively. The kappa statistics for the intraobserver agreement was 0.95 for DI assessments and 0.97 for CVMI. The value of Pearson Chi-square test value (χ^2) = 225.088 was highly significant with 20° of freedom $P = 0.001$ (highly significant). The value of contingency coefficient (C^* = 0.835) showed a highly significant association between DI and CVMI for male children. It was also clear that the lower stages of DI were associated with lower CVMI stages. Again, higher the DI stage was associated with higher the CVMI stage. Stage D included the highest percentage distribution (66.7%) at Stage 1 of CVMI; Stage E included the highest percentage distribution (66.7%) at Stage 2 of the CVMI; Stages F (45.9%), and G (54.1%) were distributed for CVMI Stage 3; DI stages G (92.3%) also included a large percentage of CVMI Stage 4 participants; and Stage H (88.9%) displayed a high percentage distribution with CVMI Stage 5 and 100% distribution with CVMI Stage 6 [Table 4]. The value of Pearson Chi-square test value (χ^2 = 221.762) at 20° of freedom, $P = 0.001$ (highly significant), showed a highly significant association between CVMI and DI for female participants [Table 5]. Lower stages of DI were associated with lower CVMI stages. Again, the higher the DI stage, the higher the CVMI stage. DI Stage D (40.0%) and E (60.0%) included the percentage distribution at Stage 1 of the CVMI; Stage E (75.0%) included the highest percentage distribution at Stage 2 of the CVMI; Stages F (51.4%) and G (48.6%) were almost equally distributed for CVMI Stage 3 [Table 5]; DI stages G (92.3%) also included a large percentage of CVMI Stage 4 participants; and Stage H (93.3%) displayed a high percentage distribution with Stage 5 and 100% distribution with CVMI Stage 6.

Table 3: Distribution of chronological ages for all participants grouped by cervical vertebrae maturation indicator stages

CVMI stage	Gender	Number of participants	Mean age (years)±SD	Gender difference (years)
Stage 1	Male	6	9.50±0.33	0.5
	Female	5	9.00±1.12	
Stage 2	Male	12	10.34±1.9	1.1
	Female	12	8.9±1.16	
Stage 3	Male	37	13.11±1.29	1.21
	Female	35	11.9±1.06	
Stage 4	Male	13	14.5±1.46	1.7
	Female	13	12.8±1.78	
Stage 5	Male	9	15.3±1.08	1.4
	Female	15	13.9±0.8	
Stage 6	Male	21	16.2±2.01	1.05
	Female	22	15.15±1.53	

CVMI: Cervical vertebrae maturation indicator; SD: Standard deviation

Table 4: Association between cervical vertebrae maturation indicator and Demirjian Index for male participants (contingency table)

CVMI	DI					
	D	E	F	G	H	Total
CVMI 1, frequency (%)	4 (66.7)	2 (33.3)	0 (0.0)	0 (0.0)	0 (0.0)	6 (100.0)
CVMI 2, frequency (%)	0 (0.0)	8 (66.7)	3 (25.0)	1 (8.3)	0 (0.0)	12 (100.0)
CVMI 3, frequency (%)	0 (0.0)	0 (0.0)	17 (45.9)	20 (54.1)	0 (0.0)	37 (100.0)
CVMI 4, frequency (%)	0 (0.0)	0 (0.0)	1 (7.7)	12 (92.3)	0 (0.0)	13 (100.0)
CVMI 5, frequency (%)	0 (0.0)	0 (0.0)	0 (0.0)	1 (11.1)	8 (88.9)	9 (100.0)
CVMI 6, frequency (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	21 (100.0)	21 (100.0)
Total, frequency (%)	4 (4.1)	10 (10.2)	21 (21.4)	34 (34.7)	29 (29.6)	98 (100.0)

Pearson Chi-square test value=225.088, df=20, $P = 0.001$ (highly significant). Contingency coefficient=0.835, P=0.001 (highly significant). CVMI: Cervical vertebrae maturation indicator; DI: Demirjian Index

Table 5: Association between cervical vertebrae maturation indicator and Demirjian Index for female participants (contingency table)

CVMI	DI					
	D	E	F	G	H	Total
CVMI 1, frequency (%)	2 (40.0)	3 (60.0)	0 (0.0)	0 (0.0)	0 (0.0)	5 (100.0)
CVMI 2, frequency (%)	0 (0.0)	9 (75.0)	1 (8.3)	2 (16.7)	0 (0.0)	12 (100.0)
CVMI 3, frequency (%)	0 (0.0)	0 (0.0)	18 (51.4)	17 (48.6)	0 (00.0)	35 (100.0)
CVMI 4, frequency (%)	0 (0.0)	0 (0.0)	1 (7.7)	12 (92.3)	0 (0.0)	13 (100.0)
CVMI 5, frequency (%)	0 (0.0)	0 (0.0)	0 (0.0)	1 (6.7)	14 (93.3)	15 (100.0)
CVMI 6, frequency (%)	0 (0.0)	0 (0.0)	0 (0.0)	0 (0.0)	22 (100.0)	22 (100.0)
Total, frequency (%)	2 (2.0)	12 (11.8)	20 (19.6)	32 (31.4)	36 (35.3)	102 (100.0)

Pearson Chi-square test value=221.762, df=20, $P = 0.001$ (highly significant). Contingency coefficient=0.828, P=0.001 (highly significant). CVMI: Cervical vertebrae maturation indicator; DI: Demirjian Index

Discussion

Developmental maturation embodies the overall biologic progression through the life. One of the most challenging aspects of pediatric dental treatment is that of being a mediator in the craniofacial growth process. The degree of skeletal development is a reflection of the degree of physiological maturation of a child.[11,12] The bone age was shown to be as important as chronological age in evaluating an adolescent's physical development.[13] In addition, the determination of skeletal age indicates how much further growth a child will attain and allows the prediction of final height.[13] Furthermore, the assessment of skeletal maturity is an important method in the evaluation, follow-up, and timing of treatment in children with growth disorders such as constitutional growth, retardation, and growth hormone deficiency as well as endocrinological diseases such as hypothyroidism, congenital adrenal hyperplasia, and precocious puberty.[14] Many methods for precise prediction of growth have been suggested.[15] Dental maturity, in particular, has the advantage of easy evaluation during routine pediatric dental practice. Radiation exposure time and dose are high when specialized radiographs are used (like hand-wrist radiographs or lateral cephalograms), making their use questionable according to the ALARA principle. The ALARA principle is especially important for children and young adults, and hence, high-radiation methods should not be used frequently to assess growth in children.

Tooth formation is proposed as a more reliable criterion for determining the dental maturation. Many studies have attempted to determine whether there is a relationship between the level of skeletal maturity and the maturation of the permanent dentition. High correlation between dental and skeletal ages was reported by Krailassiri *et al*.[11] and Engstrom *et al*.[9] On the other hand, Lewis and Garn *et al*.[8] 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. Uysal *et al*.[12] reported that second molars have the highest relationship and the third molars show the lowest correlation for both sexes. The relationship between skeletal maturity and peak adolescent height velocity is well established.[16,17] In this study, no uniformity in canine development was found relative to Stage S (appearance of ulnar sesamoid, signifies the beginning of pubertal growth spurt). Krailassiri *et al*.[11] found a low relationship between early ossification of the sesamoid bone and dental calcification Stage G and 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. They found that a large number of canines and first premolars had already attained apical closure since the MP3 cap stage for males and DP3u stage onward for females (union between diaphysis and epiphysis of distal phalanx of middle finger signifies the end of pubertal growth spurt). The mandibular second molar calcification will be a better method to evaluate the skeletal maturity. The Demirjian *et al*.[13] method was chosen for dental maturation assessment in the present study because it is based on shape criteria and proportion of root length, using the relative value to crown the height rather than the absolute length. Therefore, the foreshortened or elongated projections of developing teeth will not affect their reliability of assessment.

Cervical vertebrae are used as a reliable method of skeletal growth prediction and biological maturity indicator.[18,19] The size and shape of cervical vertebrae in growing children have gained increasing interest as a biological indicator of individual skeletal maturity. The main reason of rising popularity of this method is that the analysis of CVM is performed on the lateral radiograph of patient's head which is the type of film used routinely in orthodontic diagnosis to analyze the skeletal morphology and directional growth patterns. Several studies have indicated that each CVMI stage consistently appears earlier in girls than in boys.[11,12] Thus, the observations of the present study are in line with earlier studies. We considered the DI relative to CVMI separately for boys and girls. In this study, it was determined that at the same CVMI boys had a more close trend in DI pattern with girls. In this study, CVMI method given by Hassel and Farman is used. The analysis consisted of both visual appraisals of morphological characteristics of the three cervical vertebrae (cervical Stage 1 through CS 6, i.e., CS1 through CS6). CS1 and CS2 are prepeak stages, the peak in mandibular growth occurs between CS3 and CS4. CS6 is recorded at least 2 years after the peak.

In the present study, girls were found to mature earlier than boys, which was in agreement with the previous studies.[12] However, Chertkow and Fatti[20] reported no significant sex differences, while other studies reported an advanced trend in boys compared to girls.[1,12,16] In the present study, a highly significant association was noted between the DI of mandibular second molars and the CVMI [Tables 3 and 4]. Fishman[3] found that the appearance of the adductor sesamoid of the thumb indicates the beginning of the pubertal growth spurt, which corresponds to Stage 2 of CVMI. For both sexes, DI Stage E showed the highest percentage distribution at Stage 2 of CVMI, which signifies the prepeak of pubertal growth spurt. For both male and female participants, Stages F and G corresponded to CVMI Stages 3 and 4, which infer that DI Stages F and G represent the peak of the pubertal growth spurt. This finding supports that the suggestions of previous studies.[21,22] This study has shown that for both males and females, Stages F and G of DI correspond to Stages 3 and 4 of CVMI stages. A highly significant association (C*5 0.854 for male participants and 0.866 for female participants) was found between DI and CVMI stages.[21] In the present study, the value of contingency coefficient ($C^* = 0.835$) showed a highly significant association between DI and CVMI for male participants. Significant contingency coefficient = 0.828, $P = 0.001$ (highly significant) showing a highly significant association between CVMI and DI for female participants.

Timing is an important factor that influences treatment outcomes[23] and treatments such as growth modification, maxillary arch expansion, molar distalization, etc., depend on the age of the patient.[24] Pediatric orthodontists have a special interest in studying growth, and development of the dentofacial complex[25,26] which involves a series of dynamic changes from the intrauterine life to maturity. Although considerable variations can occur in development among children with same chronological age, mandibular second molar calcification stages can act as a reliable skeletal maturity indicator.

Conclusion

Conclusions drawn from the study are as follows:

- DI Stage E corresponds to Stage 2 of CVMI.(prepeak of pubertal growth spurt)
- Stage F and Stage G correspond to Stage 3 of CVMI indicating the start of the peak in mandibular growth which would be appropriate time to plan for treatment interventions such as functional appliances, etc.
- Stage G is also highly related to Stage 4 of CVMI (deceleration of adolescent growth spurt). Small amount of adolescent growth can be expected in this stage
- Stage H of DI which corresponds to CVMI 5 and 6 indicate that the peak of mandibular growth has already occurred and is not appropriate for functional appliances.

Unique and significant findings from the present study imply that the stages of mandibular second molar calcifications as observed under OPG give fairly accurate results and can be used as reliable indicators of skeletal maturity with the methodology suggested by DI.

Financial support and sponsorship

Nil.

Conflicts of interest

There are no conflicts of interest.

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