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RESEARCH ARTICLE

EVALUATION OF SKELETAL MATURATION USING MANDIBULAR SECOND MOLAR CALCIFICATION IN SOUTH INDIAN POPULATION

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ABSTRACT

Background: Assessment of skeletal maturity and dental development is a common clinical practice in many health professions, especially for growth modification in orthodontics and dentofacial orthopedics and for age estimation in forensic sciences. Generally, dental development can be assessed by phase of tooth eruption or stage of tooth calcification, with the latter being more reliable. An assessment of skeletal development is commonly done using hand-wrist radiographs and lateral cephalograms.

Aim: To evaluate the relationships between the stages of mandibular second molar calcification and skeletal maturity, and to evaluate whether second molar calcification stages can be used as a reliable diagnostic tool to determine skeletal maturity.

Materials and Methods: Panoramic radiograph and lateral cephalometric radiographs of 200 subjects was analysed. Tooth calcification was rated according to the Demirjian Index, in which one of eight stages of calcification (A to H) was assigned to the tooth. Evaluation of Cervical Vertebrae Maturity on Lateral Cephalogram CVMI was done according to Hassel and Farman.

Results: A highly significant association was found between DI and CVMI. DI stage E corresponded to stage 2 of CVMI (pre–peak of pubertal growth spurt) and DI stages F corresponded to stages 3 CVMI (peak of pubertal growth spurt). DI stage G and H was associated with stages 4, 5 and 6 of CVMI (end of pubertal growth spurt).

Conclusion: There exists a highly positive correlation between DI of mandibular 2nd molars and CVMI, Stage F of DI with the root length equal to or greater than the crown height, corresponds to stage 3 of CVMI indicating the start of peak in mandibular growth which would be appropriate time to plan for functional appliances. Stage G and H of DI with partially to completely closed apex corresponding to CVMI 4, 5 and 6 indicates that peak of mandibular growth has already occurred and suggests insignificant/no remaining growth.

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INTRODUCTION

Assessment of skeletal maturity and dental development is a common clinical practice in many health professions, especially for growth modification in Orthodontics and dentofacial orthopaedics and for age estimation in forensic sciences.

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An understanding of growth events is important in the practice of clinical orthodontics. Maturational status can have considerable influence on diagnosis, treatment goals, treatment planning and the eventual outcome of orthodontic treatment. Prediction of both the time and the amount of active growth, in the craniofacial complex, would be useful to the orthodontist. Orthodontist can modulate jaw growth during treatment to improve the dentofacial outcome, but only to the extent that the patient is growing. This is especially true when treatment considerations are based strongly on the facial growth such as the use of extra oral traction, functional appliances, selection of orthodontic retention and orthognathic surgery. Many researchers indicated that chronological age is not a reliable indicator to evaluate maturi,ty status of a child. (Hunter, 1966; Fishman, 1979) Chronological age does not address the differences in the timing, duration, and extent of adolescence between the sexes and among individuals within the same sex (Tanner, 1962; Van der Linden, 1986).

Physiologic age is estimated by the maturation of one or more tissue systems, and it is best expressed in terms of each system studied. Physiologic age can be estimated by somatic, sexual, skeletal, and dental maturity. The use of teeth for determining age has its origin 170 years ago when tooth eruption was first used for dental age estimation in connection with child labour. In response to the need for age estimation of factory children who were not allowed to be employed under the age of nine and with a restricted working time between 9 and 12 years of age. (Cameriere *et al*., 2007; Bergersen, 1972) The purpose of the present research is to determine if biological age, as assessed from cervical vertebral maturity and/or tooth mineralization, have any predictive merit in anticipating the amount of facial growth during the course of orthodontic treatment. Substituting bone age or dental age for chronological age should then improve the association between age and growth because the variability of 'age' is smaller when using a physiological instead of a chronological measure of maturity.

MATERIALS AND METHODS

The sample was retrospectively selected from the records of Department of Orthodontics and Dentofacial Orthopedics. Panoramic radiograph and lateral cephalometric radiographs of 200 subjects were collected. The inclusion criteria includes chronological age ranging from 9 to 18 years, normal overall growth and development, absence of abnormal dental conditions, such as impaction transposition, congenitally missing teeth and absence of previous history of trauma or disease in face and neck region.The chronological age for each subject was obtained by referring to the birth date in the personal information section of each patient's chart. Radiographic assessments of dental and skeletal maturity were performed simultaneously. Two examiners performed all the dental maturation assessment and the skeletal maturity assessment using panoramic radiograph and lateral cephalogram respectively. Evaluation of Dental Maturity on Panoramic Radiograph was done using the mandibular left second molar as a sample. Tooth calcification was rated according to the index described by Demirjian *et al*. Demirjian Index [DI] (Demirjian *et al*., 1973), in which one of eight stages of calcification (A to H) was assigned to the tooth (Table 1). Evaluation of Cervical Vertebrae Maturity on Lateral Cephalogram CVMI was done by classifying C2, C3 and C4 into six groups depending on their maturation patterns on the lateral cephalogram using the classification of Hassel and Farman (Hassel and Farman, 1995) (Table 2)

Table 1. Dental calcification stages using Demirjian Index (DI)

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, and no pulp horns are visible.
Stage D	Crown formation has been completed to the level of the cementoenamel 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. The periodontal membrane surrounding the root and apex is uniform in width throughout.

Table 2. Cervical vertebrae maturation stages (CS)

Cervical stage 1 (CS1)	The lower borders of all the three vertebrae (C2-C4) are flat. The bodies of both C3 and C4 are trapezoid in shape (the superior border of the vertebral body is tapered from posterior to anterior). The peak in mandibular growth will occur on average 2 years after this stage.
Cervical stage 2 (CS2)	A concavity is present at the lower border of C2 (in four of five cases, with the remaining subjects still showing a cervical stage 1). The bodies of both C3 and C4 are still trapezoid in shape. The peak in mandibular growth will occur on average 1 year after this stage.
Cervical stage 3 (CS3)	Concavities at the lower borders of both C2 and C3 are present. The bodies of C3 and C4 may be either trapezoid or rectangular horizontal in shape. The peak in mandibular growth will occur during the year after this stage.
Cervical stage 4 (CS4)	Concavities at the lower borders of C2, C3, and C4 now are present. The bodies of both C3 and C4 are rectangular horizontal in shape. The peak in mandibular growth has occurred within 1 or 2 years before this stage.
Cervical stage 5 (CS5)	The concavities at the lower borders of C2, C3, and C4 still are present. At least one of the bodies of C3 and C4 is squared in shape. If not squared, the body of the other cervical vertebra still is rectangular horizontal. The peak in mandibular growth has ended at least 1year before this stage.
Cervical stage 6 (CS6)	The concavities at the lower borders of C2, C3, and C4 still are evident. At least one of the bodies of C3 and C4 is rectangular vertical in shape. If not rectangular vertical, the body of the other cervical vertebra is squared. The peak in mandibular growth has ended at least 2 years before this stage.

Statistical analysis

All the data were analysed using SPSS software version 16 SPSS Inc; Chicago, Illinois, USA. The descriptive statistics were calculated by determining the means and standard deviations of the chronological ages for the six stages of CVMI. To test the reproducibility of the assessments of DI and CVMI interobserver and intraobserver agreement for both investigators were determined in terms of the weighted kappa statistics for DI and CVMI. To study the relationship between DI and the CVMI, the frequency and the percentage distribution of the stages of calcification were recorded for each tooth, and these were calculated separately for male and female subjects. Chi-square test and Pearson contingency coefficient were estimated to determine the relationships between DI and CVMI.

RESULTS

CVMI stages 1-4 appeared earlier in females than males whereas stages 5 and 6 emerged at similar age in both genders (Table 3). The inter-observer agreement (DI=0.84, CVMI=0.87) and intra-observer agreement (DI=0.83, CVMI=0.89) was obtained using Kappa statistics, displaying a good reproducibility of assessments.

Table 3. Distribution of Chronological Ages for All Subjects Grouped by CVMI Stages

CVMI stage	Gender	No of Subjects	Chronological Age (y)	
			Mean	SD
Stage 1	Male	16	10.13	0.93
	Female	9	9.22	0.42
Stage 2	Male	12	11.25	1.68
	Female	16	10.31	1.04
Stage 3	Male	20	12.55	1.80
	Female	11	11.54	1.30
Stage 4	Male	20	13.8	1.54
	Female	23	13.34	1.57
Stage 5	Male	15	14.86	1.58
	Female	11	15.54	0.98
Stage 6	Male	18	17	1
	Female	29	17.03	1.15
	Total	200 (101 Males, 99 Females)		

Table 4. Association between CVMI and DI for Male Subjects (Contingency Table)

	DI									
			B	C	D	E	F	G	H	Total
CVMI	Stage 1	Frequency	1	4	9	2				16
		Percentage	6.2%	25.0%	56.2%	12.5%				100.0%
	Stage 2	Frequency		2	3	3	4			12
		Percentage		16.7%	25.0%	25.0%	33.3%			100.0%
	Stage 3	Frequency			1	4	8	5	2	20
		Percentage			5.0%	20.0%	40.0%	25.0%	10.0%	100.0%
	Stage 4	Frequency					4	15	1	20
		Percentage					20.0%	75.0%	5.0%	100.0%
	Stage 5	Frequency				1		9	5	15
		Percentage				6.7%		60.0%	33.3%	100.0%
	Stage 6	Frequency						3	15	18
		Percentage						16.7%	83.3%	100.0%
	Total	Frequency	1	6	13	10	16	32	23	101
		Percentage	1.0%	5.9%	12.9%	9.9%	15.8%	31.7%	22.8%	100.0%

X^2= 149.43; Pearson contingency coefficient (C*) = 0.851; P < 0.001 (significant).

Table 5. Association between CVMI and DI for Female Subjects (Contingency Table)

CVMI	DI								
			C	D	E	F	G	H	Total
	Stage 1	Frequency	3	6					9
		Percentage	33.3%	66.7%					100.0%
	Stage 2	Frequency		9	4	2	1		16
		Percentage		52.2%	25.0%	12.5%	6.2%		100.0%
	Stage 3	Frequency		1	3	4	3		11
		Percentage		9.1%	27.3%	36.4%	27.3%		100.0%
	Stage 4	Frequency		1	2	4	15	1	23
		Percentage		4.3%	8.7%	17.4%	65.2%	4.3%	100.0%
	Stage 5	Frequency			1		4	6	11
		Percentage			9.1%		36.4%	54.5%	100.0%
	Stage 6	Frequency					2	27	29
		Percentage					6.9%	93.1%	100.0%
	Total	Frequency	3	17	10	10	25	34	99
		Percentage	3.0%	17.2%	10.1%	10.1%	25.3%	34.3%	100.0%

X^2= 154.98; Pearson contingency coefficient (C*) = 0.882; P < 0.001 (significant).

Association between DI and CVMI for male Subjects: (Table 4)

A highly significant association between DI and CVMI for male participants was observed (C*=0.851, x^2=149.43, p<0.001). The lower stages of DI were associated with lower CVMI stages. Stage D of DI included the highest percentage distribution (56.2%) corresponding to Stage 1 of CVMI. While stage F had a higher percentage distribution (33.3%), stage D and E displayed equal percentage (25%) at stage 2 of CVMI. Stage G corresponded to the higher percentage distribution in both, stage 4 (75%) and 5 (60%), whereas Stage H of DI accounted for the highest percentage (83.3%) at stage 6 of CVMI respectively.

Association between CVMI and DI for Female Subjects (Table 5)

An x^2value of 154.98 with a Pearson contingency coefficient (C*) of 0.882 (P < 0.001), indicated a significant association between DI and CVMI for female participants. In females, the

Stages of CVMI corresponded from Stage C to H of DI, unlike in males, which corresponded from a lower stage (Stage B to H). Stage D of DI included the highest percentage distribution corresponding to Stage 1 (66.7%) and stage 2 (52.2%) of CVMI. Stage H corresponded to the higher percentage distribution in both, stage 5 (54.5%) and stage 6 (93.1%). While a stronger association of DI with CVMI was observed amongst females, the DI in male participants was more advanced than females, in majority of the CVMI stages.

DISCUSSION

In the organization, differentiation, development and growth of any somatic structure, time plays a crucial role in determining the final morphological and dimensional result. In orthodontics and dentofacialorthopedics, it is becoming increasingly evident that the timing of the treatment onset may be as critical as the selection of the specific treatment protocol. Individual skeletal maturity can be assessed by means of several biologic indicators: increase in body height (Hunter, 1966), skeletal maturation of the hand and wrist (Hagg and Taranger, 1980), dental development and eruption (Lewis and Garn, 1960), menarche or voice changes (Lewis and Garn, 1960) and cervical vertebral maturation (O'Reilly and Yanniello, 1988) stage. Hence the most favourable response with the least potential morbidity shouldbe considered.

Dental age

The need for using dental maturity: Dental maturity in particular has the advantage of easy evaluation during routine dental treatment. Radiation exposure time and dose are high when specialized radiographs are used (hand-wrist radiographs or lateral cephalograms), making their use questionable according to the ALARA principle.

Need for using Demirjian index: Several methods have been described to determine dental age. One of these uses time of eruption as a parameter. According to Nolla (1960) dental eruption has been reported to be more variable than the calcification sequence in the dentition. Also, tooth emergence can be altered by local factors, systemic diseases, and nutritional habits and so the reliability of the method is questionable. Therefore, in the present study, calcification stages of teeth were preferred for determining dental maturation. High accuracy was noted with these methods when applied to Indian populations. (Rai *et al*., 2008) Foreshortened or elongated projections of developing teeth do not affect the determinations. Therefore, this method was used in this study.

Need for using mandibular second molar: Maxillary teeth were not considered because superimposition of the anatomic structures such as the palate, the inferior border of the zygomatic arch or the maxillary sinus septum would not allow the accurate assessment of stages. Most studies of the dentition have used either mandibular canines (Coutinho *et al*., 1993) or third molars (Garn *et al*., 1962) for dental age assessment, but these two parameters exhibit some drawbacks. Root formation and apex closure of mandibular canines are completed by the age of 13 years, but most children exhibit active growth up to the age of 16 to 17 years. Third molars on the other hand are the most commonly missing teeth in the human dentition and the root of the third molar tends to be less divergent and more fused, making it harder to evaluate its development according to root length, thus making them unreliable for age assessment. Thus mandibular second molar offers an advantage over other teeth because its development tends to continue over a longer period and until a later age.

Skeletal age

Skeletal maturation staging from radiographic analysis is a widely used approach to predict timing of pubertal growth, to estimate growth velocity and to estimate the proportion of growth remaining. (Flores-Mir *et al*., 2004)

Need for using cervical vertebrae: Hand-wrist radiograph is considered to be the most standardized method of skeletal assessment. (Houston *et al*., 1979; Kamal *et al*., 2006) There are some limitations in the interpretation of skeletal maturity from hand-wrist radiographs. The ossification sequence and timing of skeletal maturity within the hand-wrist area show polymorphism and sexual dimorphism, which can limit the clinical predictive use of this method. (Houston, 1980; Smith, 1980) Moreover, there are concerns about the extra radiation exposure resulting from use of this method [48] and its use must be questioned if other comparable methods of assessment are available.

Need for using the original radiographs: According to Gabriel *et al*. (Chatzigianni and Halazonetis, 2009) most of the studies that cited high-reproducibility results for the CVM method (90%) used tracings of the cervical vertebrae instead of the actual radiographs during the CVM stage process, which may introduce bias. Conventional prediction schemes of maturation indicators overestimate the developmental stage of the child and accordingly, underestimate the growth potential. Racial variations between the calcification stages of individual teeth and skeletal maturity have been reported in the previous studies. (Demirjian *et al*., 1985) Therefore, this study was carried out to investigate the relationship between the stages of calcification of mandibular second molar teeth and skeletal maturity stages in davangere population.

Correlations between tooth calcification stages and skeletal maturity indicators

Many studies have reported high correlation between tooth calcification stages and skeletal maturity indicators, which would probably allow clinicians to more easily identify pubertal growth stages from panoramic radiographs. (Coutinho *et al*., 1993) On the other hand, Lewis and Garn (1960) Garn *et al*. (1962) and Tanner (1962) reported low or insignificant correlations between skeletal and dental maturation. In the present study chronological age distribution into six stages of CVMI showed that each stage appeared earlier in femaleswhen compared with males. This observation agrees with preceding studies by Krailassiri *et al*. (2002) and Uysal *et al*. (2004) who found that each CVMI stage consistently appears earlier in girls than in boys. Females had a higher distribution towards late dental development in this study at the same cervical maturation stage. Therefore, a sex distinction must be made in estimating facial growth according to dental maturity. The DI and CVMI was evaluated separately for male and female subjects. Present study revealed majority of CVMI stages in male subjects had a more advanced trend in DI and the opposite pattern was present in female subjects and a highly significant association between the DI of mandibular second molars and the CVMI was established. On the contrary findings of Krailassiri *et al*. (2002) and Uysal *et al*. (2004) indicated that the maturation patterns of tooth development in male subjects tend to be more advanced versus female subjects in relation to skeletal maturity stages. Chertkow (1980) reported that a markedly more advanced trend in tooth calcification was evident among both black and white boys. The relationship between skeletal maturity and peak height velocity (PHV) is well established (Bjork and Helm, 1967) Fishman (Fishman, 1987), Hagg (1980) found that the appearance of the adductor sesamoid of the thumb indicate the beginning of the pubertal growth spurt (onset of PHV), which corresponds to stage 2 of CVMI. (Chertkow and Fatti, 1979) In the present study DI stage D, E and F showed the highest percent distribution at stage 2 of CVMI, which signifies the pre-peak of pubertal growth spurt. Stage 3 of CVMI is very crucial for optimal treatment timing as it represents the peak of pubertal growth and peak in mandibular growth that occurs during a year after this stage. Bjork and Helm (1967) found that the MP3cap stage heralds the peak of the pubertal growth spurt, which corresponds to Fishman's skeletal maturity indicator 6 (stage 3 of the CVMI) (Kamal *et al*., 2006) In the previous studies done by Sushil Kumar and Anu Singla (2012) demonstrates for both males and females, stages F and G of DI correspond to stages 3 and 4 of CVMI, but the current study shows a clear differentiation that stage F corresponds to stage 3, which helps in accurate and precise identification of growth status and to evaluate optimal treatment timing rather than overlapping with stages F and G, which makes it difficult to precisely differentiate the growth. In Fishman's skeletal maturity indicator 11 corresponds to CVMI stage 5. In the current study, males showed that stage G corresponds to CVMI stages 4 and 5 (peak in mandibular growth has occurred within 1 or 2 years before this stage). Fishman's skeletal maturity indicator 11 corresponds to CVMI stage 5 and the fusion of the epiphysis and diaphysis of the radius (which signifies the end of growth). In the present study both males and females displayed a high percent distribution of CVMI stage 6 for DI Satge H The DI stage H suggests insignificant/no remaining adolescent growth.

Conclusion

- There exists a highly positive correlation between DI of mandibular 2nd molars and CVMI
- Stage 2 of CVMI which signifies the prepubertal growth spurt showed highest percent distribution at Stage D, E and F of DI.
- Stage 3 of CVMI indicating the start of peak in mandibular growth which would be appropriate time to plan for functional appliances showed highest percent distribution at stage F of DI which indicates the root length equal to or greater than the crown height.
- Stage 4 of CVMI indicating the peak of mandibular growth has occurred within 1 to 2 years showed highest percent distribution at Stage G of DI which indicates partially closed root apex
- Stage 5 and 6 of CVMI indicating that peak of mandibular growth has already occurred and suggesting insignificant and no remaining growth showed highest percent distribution at Stage G and H of DI which indicates partial to completely closed root apex.

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