ORIGINAL RESEARCH

Accuracy of Different Dental Age Estimation Methods Using Cone Beam Computed Tomography: A Comparative Study

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Abstract

Background: Age assessment is useful in various fields of dentistry due to its ability to influence the planning of dental treatments. Dental age estimation methods are specifically based on age-related variables observed in two-dimensional (2D) radiographs in the dentition in terms of the time of emergence and are considered reliable in determining the chronological age; however, the inevitable problems of orientation errors found in 2D can be eliminated using cone beam computed tomography (CBCT).

Objective: This study aimed to compare the accuracy of different radiological dental age estimation methods using CBCT in relation to the chronological age of children.

Materials and methods: A total of 100 CBCT images of patients in the age-group of 8–15 years requiring orthodontic treatment were obtained from December 2019 to August 2022. The exact chronological age was determined through valid proof, that is, aadhar card or birth certificate. The dental age of the children was assessed using all four methods—Nolla's method (NM), Demirjian method (DM), Schour and Massler (S&M), and Cameriere method (CM).

Results: The results found that NM underestimated the mean age by 0.24 years, while DM overestimated the mean age by 0.82 years. Both showed statistically significant differences based on the standard deviation (SD) ($p < 0.05$). S&M and CM also overestimated the mean age by 1.16 years and 2.75 years respectively, but with statistically nonsignificant differences ($p > 0.05$).

Conclusion: Among the four tested radiographic methods, the best accuracy was found with NM, which tended to underestimate but was closest to the chronological age. CBCT provided better age estimation values without image distortion.

Keywords: Cone beam computed tomography, Demirjian method, Nolla's method, Schour and Massler.

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Introduction

Age determination plays an important role in many domains, such as pediatric dentistry, orthodontics, forensic sciences, and in the identification of people in circumstances involving false information about illegal immigrants and unidentified bodies.[1] Anthropometry, dental age, chronological age, and other factors can all be used for age estimation.[2]

In dentistry, dental age estimation is done using different methods such as morphological, biochemical, and radiological methods. However, these dental age determination methods are mainly based on the subjective prediction of the radiological aspects of stages of dental development.[3] The different radiographical methods used for dental age estimation in children and adolescents include the Schour and Massler (S&M) method (1941), Nolla's method (NM) (1960), Demirjian method (DM) (1973), and Cameriere method (CM) (2006).

The oldest method used for dental age estimation in children and adolescents was the S&M method, in which the calcification stages of teeth on radiographs were compared with standards.[4] CM and NM developed a method in 1963 that assessed the mineralization of permanent dentition in 10 stages through which every tooth passed. It was used to analyze the development of each tooth of the maxillary and mandibular arch.[5]

Demirjian et al. reduced the number of stages as they only evaluated seven left mandibular permanent teeth and identified eight stages (A–H) of tooth mineralization.[6] More recently, in 2006, Cameriere et al. introduced a technique based on the correlation between age and the measuring of open apices in teeth to determine the dental age in children.[7] Numerous studies have been conducted to assess the dental age using orthopantomogram; however, CBCT has not been used to date.[8,9]

Cone beam computed tomography (CBCT) has high reliability and reproducibility because it generates multiplanar reformatted (MPR) pictures, enabling two-dimensional (2D) views in the axial,

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coronal, and sagittal planes. This effectively addresses issues with orientation errors and overlaps.[10,11]

However, to date, there are hardly any studies that have compared these four dental age estimation methods using CBCT. Thus, the present study was planned to compare the accuracy of commonly used different radiological dental age estimation methods using CBCT in relation to the chronological age of children.

Materials and Methods

A total of 100 children aged 8–15 years undergoing orthodontic intervention were selected from the Outpatient Departments of Subharti Dental College, Meerut, Uttar Pradesh, India, from December 2019 to August 2022, and were advised CBCT. The cases excluded were medically compromised children with a history of premature extraction or congenitally missing permanent teeth. In the CBCT scans, a complete maxillary and mandibular view was captured, and image analysis was conducted. The exact chronological age was determined through valid proof, that is, aadhar card/birth certificate (not known to the operator). Informed consent was obtained from the parents/guardians of the children participating in the study. The dental age of 100 children using CBCTs was assessed using all four methods, that is, NM,[5] DM,[6] S&M,[4] and CM.[7]

In NM, All the teeth in the CBCT were analyzed and designated with a development stage of left mandibular teeth, as given in Figure 1. Values obtained for mandibular teeth were added, and this sum was matched with Table 1 for the translation of supplemental value into the dental age. Based on the growth of seven teeth from the left side of the mandible, DM calculated the dental age of the patient, and all teeth were rated on a scale A–H (Fig. 2 and Table 2). In the S&M method, age estimation was done by directly comparing the stages of

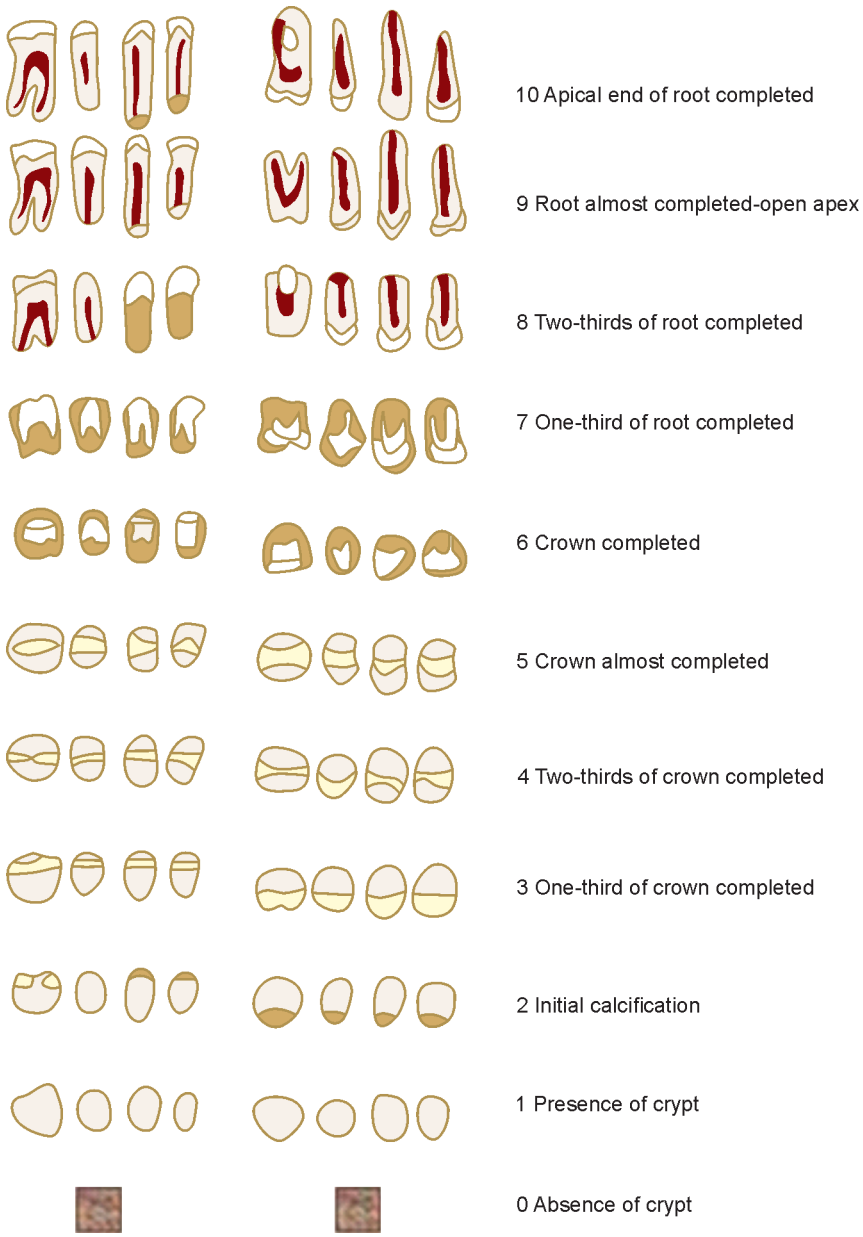

Fig. 1: Stages of development given by Nolla[5]

Table 1: Nolla's age norms for maxillary and mandibular teeth of boys and girls[5]

Age in years	*Sum of stages of 7 mandibular teeth (boys)*	*Sum of stages of 7 mandibular teeth (girls)*	*Sum of stages of 7 maxillary teeth (boys)*	*Sum of stages of 7 maxillary teeth (girls)*	*Sum of stages of 14 teeth (boys)*	*Sum of stages of 14 teeth (girls)*
3	22.3	24.6	18.9	22.2	41.2	46.8
4	30.3	32.7	26.1	29.6	56.4	62.3
5	37.1	40.1	33.1	37.9	70.2	78.0
6	43.0	46.6	39.6	43.4	82.6	90.0
7	48.7	52.4	45.5	49.5	94.2	101.9
8	53.7	57.4	50.8	54.9	104.5	112.3
9	57.9	58.4	55.5	59.6	113.3	118.0
10	61.5	64.8	59.5	63.4	121.0	127.7
11	64.0	66.3	62.6	64.0	126.6	130.3
12	66.3	67.9	65.3	67.8	131.6	135.7
13	67.8	68.9	67.3	69.2	135.1	138.1
14	69.0	69.4	68.5	69.7	137.5	139.1
15	69.7	69.8	69.3	69.8	139.0	139.6
16	70.0	70.0	70.0	70.0	140.0	140.0
17	70.0	70.0	70.0	70.0	140.0	140.0

	Stage	Characteristics
	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 dentin 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 a 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.

Fig. 2: Demirjian's chart of tooth development[6]

tooth development on CBCT using the S&M chart (Fig. 3), which depicted the development of deciduous and permanent teeth in seven stages. Similar to DM, Cameriere determined the dental age using seven left mandibular teeth based on the relation between the age and the measurement of open apices in teeth using seven left mandibular teeth and derived a regression

Table 2: Maturity scores given for each stage by Demirjian[6]

Tooth	*0*	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
Stages for boys									
M2	0.0	2.1	3.5	5.9	10.1	12.5	13.2	13.6	15.4
M1				0.0	8.0	9.6	12.3	17.0	19.3
PM2	0.0	1.7	3.1	5.4	9.7	12.0	12.8	13.2	14.4
PM1			0	3.4	7.0	11.0	12.3	12.7	13.5
C				0.0	3.5	7.9	10.0	11.0	11.9
I1				0.0	3.2	5.2	7.8	11.7	13.7
I2					0	1.9	4.1	8.2	11.8
Stages for girls									
M2	0.0	2.7	3.9	6.9	11.1	13.5	14.2	14.5	15.6
M1				0.0	4.5	6.2	9.0	14.0	16.2
PM2	0.0	1.8	3.4	6.5	10.6	12.7	13.5	13.8	14.6
PM1			0	3.7	7.5	11.8	13.1	13.4	14.1
C				0.0	3.8	7.3	10.3	11.6	12.4
I1				0.0	3.2	5.6	8.0	12.2	14.2
I2					0	2.4	5.1	9.3	12.9

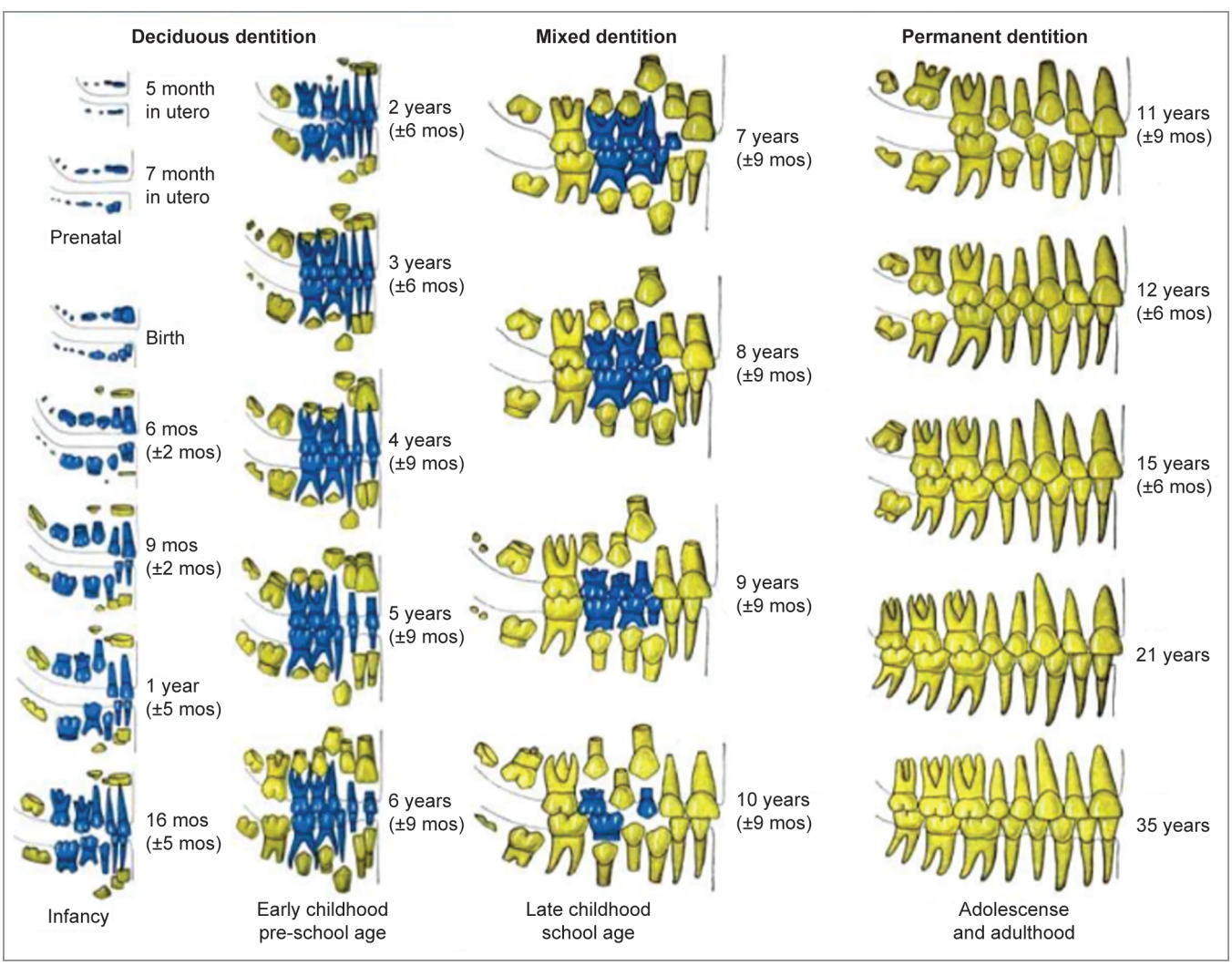

Fig. 3: Schour and Massler's chart of tooth development[4]

formula (age = 8.971 + 0.375 g + 1.631 (5) + 0.674 No − 1.034 s − 0.176 (s) (No). g = 1 for boys, g = 0 for girls, No = the number of teeth with root completed with apical ends closed, s = the sum of normalized open apices). Determined ages were compared with the chronological age.

Results

Data obtained was calculated, compared, and statistically analyzed using the Statistical Package for the Social Sciences (SPSS) software (SPSS® for Windows, version 19.0). Mean, standard deviation (SD), frequency, and Wilcoxon signed-rank test were used for the analysis of the data. The sample size was calculated using the following formula:

$$N = \frac{(r+1)(Za/2)+(Z_{1-B})\sigma}{rd^2}$$

The mean chronological age was found to be 11.80 years, and the mean age estimated using NM, DM, S&M, and CM was found to be 11.56, 12.62, 12.96, and 14.55 years, respectively (Table 3). By NM, the mean age estimated was 0.24 years less than the chronological age and had more SD than the chronological age. On comparing the other methods, the mean age difference by DM, S&M, and CM was 0.82, 1.16, and 2.75 years more than the chronological age (Table 3 and Fig. 4). Hence, it was concluded that the mean difference in age estimation was lesser in NM compared to other methods. Therefore, NM is a more accurate method for estimating the chronological age, whereas DM, S&M, and CM showed slightly moderate, substantial, and fair agreement with that of chronological age.

Table 4 shows the comparison of mean age difference between different radiographical methods of age estimation. There was a significant difference between NM and other methods of dental age estimation, with NM showing lesser age (11.56 years), but the differences were statistically significant ($p < 0.05$). DM underestimated the age (12.62 years) compared to the S&M method (12.96 years) and CM (14.55 years), but the differences were statistically significant ($p < 0.001$). Age estimated using S&M (12.96 years) was significantly less compared to the CM (14.55 years).

Table 5 depicts the validity of each dental age estimation method and clarifies that the best accuracy was found in NM (mean absolute error: 0.562 years) with the tendency to overestimate chronological age (mean error: 0.24 years) and with high precision (SD: 0.82 years). CM was the least precise method (mean absolute error: 3.396 years) with a tendency of overestimation (ME: –2.75 years) and moderate precision (SD: 3.27 years).

Table 3: Comparison of chronological age with age estimated using different methods (in years)

Pair	*Method*	*Mean*	*SD*	*Difference*	*p-value*
Pair 1	Chronological age	11.80	2.02	0.24	0.004*
	NM	11.56	2.21		
Pair 2	Chronological age	11.80	2.02	−0.82	<0.001*
	DM	12.62	1.88		
Pair 3	Chronological age	11.80	2.02	−1.16	0.396
	S&M	12.96	1.87		
Pair 4	Chronological age	11.80	2.02	−2.75	<0.001*
	CM	14.55	3.22		

Paired *t*-test; *, indicates significant difference at $p \leq 0.05$

Discussion

The time period that an organism or individual survives after birth is referred to as chronological age and is recorded by registering the birth date of an individual. This age is referenced throughout an individual's life.[12] Since a child's chronological age is influenced by a number of elements, including genetic, epigenetic, environmental, nutritional, hormonal, and more, it plays a significant role in determining their maturational state. However, the assessment of age is useful in planning orthodontic treatment, particularly with myofunctional appliances, to formulate the treatment plan,

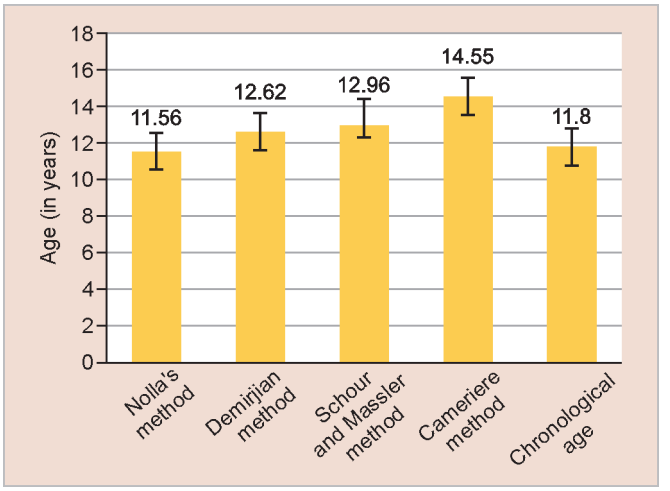

Fig. 4: Comparison of different age estimation methods in relation to chronological age (in years)

Table 4: Comparison between different methods of age estimation (in years)

Pair	*Method*	*Mean*	*SD*	*Difference*	*p-value*
Pair 1	NM	11.56	2.21	−1.06	<0.001*
	DM	12.62	1.88		
Pair 2	NM	11.56	2.21	−0.30	0.042*
	S&M	12.96	1.87		
Pair 3	NM	11.56	2.21	−2.99	0.004*
	CM	14.55	3.22		
Pair 4	DM	12.62	1.88	0.66	0.001*
	S&M	12.96	1.87		
Pair 5	DM	12.62	1.88	−1.93	<0.001*
	CM	14.55	3.22		
Pair 6	S&M	12.96	1.87	−2.59	<0.001*
	CM	14.55	3.22		

Paired *t*-test; *, indicates significant difference at $p \leq 0.05$

Table 5: Validity of each dental age estimation method

Method	*SD*	*ME*	*MAE*
NM	0.82	−0.24	0.562
DM	2.25	0.82	1.749
S&M	1.87	1.16	1.424
CM	3.27	2.75	3.396

MAE, mean absolute error as a measure of method's accuracy; ME, mean error as a measure of method's bias; SD, standard deviation as a measure of accuracy

and it also serves as a source of complementary information for pediatricians.[6]

Dental age estimation is done by comparing the dental development status of an individual of unknown age with previously published developmental surveys. In the present study, the dental age in all the children was assessed using four methods, that is, NM,[5] DM,[6] SM,[4] and CM,[7] and were compared with the exact chronological age, which was determined through valid proof, that is, aadhar card/birth certificate (not known to the operator). Dental age estimation using 2D radiological techniques was not able to provide enough information to establish a correct interpretation.[8] Therefore, the present study employed the use of CBCT for age estimation.

When chronological age was compared with NM, it underestimated the age (mean age = 11.80 years), and this difference was statistically significant ($p = 0.004$) ($p < 0.05$). The NM offers more interstage subdivisions and allows for better interstage distinction of dental maturity, which may be one of the reasons it has proven to be a more significant predictor.[7]

Similar results were observed in a study conducted by Kirzioglu and Ceyhan,[13] who compared NM, Havikko, and DM in healthy Turkish children between 7 and 13 years old, and the authors concluded that the NM was more accurate than Havikko and DM in the Turkish population.

When chronological age was compared with the DM, it was observed that DM overestimated the chronological age; however, the difference was statistically significant ($p < 0.05$). This could be attributed to the reason that in the DM, the stages are clearly defined, and they facilitate the classification of the development of individual teeth.[6]

When S&M method and Cameriere were compared with the chronological age, both the methods overestimated the age, but the result was statistically nonsignificant ($p < 0.05$). The possible explanation for this could be that S&M omitted several age categories in which tooth development is highly variable. Also, the chart does not have separate surveys for males and females.[4] Similarly, CM is based on mathematical measurements and formulae with objective, statistical, and numerical approaches that maximize possible errors of interpretation, which might result in lower reliability. Thus, these methods were not found to be more reliable for exact age estimation.[14]

In the intercomparison of NM with the other methods, the NM underestimated the mean age difference compared to other methods, and the result was statistically significant ($p < 0.001$). The results were in accordance with several studies[15,16] in which the NM was found to be a more accurate method for estimating dental age than the DM.

When the DM was compared with other radiographic methods, it was found that the DM underestimated the age compared to S&M and CM but overestimated the mean age compared to the NM. Similar results were obtained in the study by Boel and Bahri[17] in which the S&M method was compared to the DM, and it was concluded that the DM more accurately estimated the chronological age.

Wolf et al.[18] compared CM with DM and observed that DM showed more appropriate results for dental age estimation, and CM showed a higher inaccuracy in all age-groups.

When a comparison of S&M method with other methods was done, it was demonstrated that it overestimated the age as compared to the NM and DM and underestimated the age compared to CMs, whereas CM overestimated the age compared to other radiological methods.

For radiographic imaging in age estimation, a number of studies using 2D images have been conducted; however, the teeth undergo distortion by overlapping of the dental structure, but more recently, 3D radiographs (CBCT) with a focus on age estimation have emerged. Hence, an investigation with the applicability of 3D imaging in age estimation seems more reasonable.[19] Thus, in the present study, CBCT, a 3D image was used to obtain more accurate results.

The results in the present study thus supported that the NM is suitable and reliable for estimating the chronological age in the age-group of 8–15 years compared to other methods. The accuracy of an age-estimating method is influenced by three factors—individual variability in biological development, the quality and applicability of reference standards, and the possibility of correctly interpreting the staging of teeth. Further research is required to check the validity, reliability, and applicability of this method in different populations across the world.

Conclusion

The present study implies that all four radiographic methods, including NM, DM, S&M, and CM, were able to determine approximate age using CBCT. The best accuracy was found in the NM, with a tendency to underestimate the chronological age, followed by the DM, with a tendency to overestimate the chronological age.

Clinical Significance

Evaluation of growth and development in children based on general and oral developmental status and dental age is important for appropriate diagnosis and treatment decisions in pediatric dentistry.

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