

Chronological and Dental Age Estimation by Measurements of Open Apices using CBCT and OPG in Paediatric Population (7 to 15 years) – A Digital Comparative Study

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Received: 25th Aug, 2026 | Revised: 1st Sep, 2026 | Accepted: 5th Sep, 2026 | Available Online: 17th Sep, 2026

ABSTRACT

Background & Objectives: Determining dental age is crucial in clinical and medicolegal settings, and radiographic methods are valuable for accurate age estimation in children. This study aimed to estimate dental age using OPG and CBCT based open apex measurements, compare it with chronological age in 7–15-year-old children, and evaluate the accuracy and relative superiority of the Indian specific Cameriere method when applied to CBCT.

Method: Radiographic images of 100 subjects aged 7–15 years were analysed. The seven mandibular permanent teeth of the left side were evaluated for open and closed apices on both OPG and CBCT, and dental age was estimated using the Indian specific Cameriere method. From the subjects' birth records, chronological age was calculated.

Results: The mean chronological age was 10.700 ± 2.480 years, with no significant gender difference ($p = 0.64$). Both OPG and CBCT underestimated dental age by 1.534 and 1.388 years, respectively ($p < 0.001$ each), the latter being slightly closer to chronological age. Mean dental age was 9.166 ± 1.995 years on OPG and 9.312 ± 2.029 years on CBCT, with CBCT producing marginally higher values (mean difference -0.146 years, $p < 0.001$). Dental age from both modalities showed very strong positive correlation with chronological age ($\rho = 0.91$, $p < 0.001$), indicating reliable, proportionate age related increases. Overall, both OPG and CBCT provided highly correlated and clinically useful dental age estimates, with CBCT demonstrating greater accuracy and slightly less underestimation compared with OPG.

Conclusion: The results from this study, which employed the Indian-specific Cameriere formula, reveal that both OPG and CBCT imaging modalities are effective in dental age estimation. OPG seems appropriate for initial evaluation and screening due to the ease and simplicity of the imaging modality. Alternatively, the higher resolution and three-dimensional imaging associated with the CBCT modality make it more appropriate for accurate and precise dental age calculation.

Keywords: Dental Age estimation; Chronological Age estimation; OPG; CBCT; Cameriere method; Open apices

How to cite this article: Divyabharathi K^{1*} Dr. G. Roopashri². Chronological and Dental Age Estimation by Measurements of Open Apices using CBCT and OPG in Paediatric Population (7 to 15 years) – A Digital Comparative Study. Int J Drug Deliv Technol. 2026;16(83s):821-830. DOI: 10.25258/ijddt.16.83s.93.

INTRODUCTION

Forensic Odontology is defined as the dental speciality that manages, examines, evaluates, and presents dental evidence to serve the legal system and the interests of justice by the Fédération Dentaire Internationale (FDI) ¹. For forensic purposes, the problem related to estimation of age concerns how close true age is to the threshold age of criminal responsibility in various countries ². Radiography, being a non-destructive method, also

plays a crucial role in forensic odontology to uncover hidden facts that cannot be seen by means of physical examination ³. Forensic odontology has mainly used periapical and panoramic radiographs, but advanced imaging like cone beam computed tomography (CBCT) has been underutilised for dental age estimation ^{4,5}. Various methods exist for estimating age in children and pubescents. In this study, the Cameriere open apex method was employed, as it has been shown to provide greater

accuracy compared to other techniques⁶. Rai et al. found Cameriere's European formula to be inaccurate for the Indian population; hence, a population-specific Indian formula accounting for regional variations was developed and utilized in the present study⁷. Kaplan T. T. et al. (2024), in Turkish children aged 6–14 years, demonstrated that Cameriere's European formula applied to CBCT and panoramic radiographs showed high correlation, low mean absolute error, and minimal overestimation of chronological age, confirming CBCT as an equally accurate and reliable alternative. Although these findings support the applicability of Cameriere's method in Turkish children, its validity in the Indian population remains insufficiently established, highlighting the need for population-specific studies⁸. Hence, this study aimed to estimate dental age by evaluating open apices on OPG and CBCT, and compare the same with the chronological age of children aged between 7 and 15 years. Also, this study evaluates the accuracy of CBCT in estimating dental age using Cameriere's method, the Indian-specific formula and the usefulness of CBCT in dental age estimation over Orthopantomography.

MATERIALS AND METHODS:

The study comprised 100 subjects from the paediatric population aged 7 to 15 years who visited the Department of Oral Medicine and Radiology. OPG and CBCT images obtained as part of routine diagnosis and treatment were used in the study. A detailed case history and thorough clinical examination of the subjects were carried out to ensure the selection of ideal subjects. Radiographs and scans of healthy children aged 7 to 15 years who were referred for orthodontic and pedodontic treatment, with no agenesis of teeth or jaws and no history of extraction of permanent teeth in the left lower quadrant, were included in this study. Children with premature birth, facial asymmetry, congenital anomalies, developmental disturbances of the jaws and teeth, oligodontia, hypodontia, anodontia, previous orthodontic or root canal treatment, or a history of trauma or surgery in the dentofacial region were excluded from the study. OPG was taken using Kodak 8100SC Digital panoramic and Cephalometric system (73 kVp, 10 mA, 10.8 seconds) using radiation protection protocols as per the guidelines provided by the manufacturer of the X-ray unit. The same subjects were then subjected to CBCT scans of the left mandible, which were performed by the Rotograph EVO 3D CBCT machine [VILLA SISTEMI MEDICALI S.p.A., Buccinarco (MI), Italia] with the field of view (FOV) modes of 8.5 x 8.5 cm and 0.17 mm slice thickness. The exposure time was 11.2 seconds. The tube voltage was 66-70 kVp, and the tube current was 8 mA. The chronological age of all the subjects was determined by finding the difference between the date of birth and the date of taking the radiograph. Chronological Age (years) =

Date of Radiograph–Date of Birth/365.25. Digital Orthopantomography (OPG) were recorded on a computer file and processed using a computer-aided drafting program (Masterview 4.5.6.4). For each CBCT scan, volumetric data were generated. All the images were analyzed using OnDemand software. The volumetric data was displayed in MPR view, which displays coronal, sagittal and axial sections. The coronal section was set to obtain the mesiodistal section, and the sagittal section was set to obtain the buccolingual section on the widest and highest plane of the specific tooth. The measurements of the open apex and the length of each tooth with incomplete root development were calculated. The seven permanent mandibular teeth of the left side, except third molars, were evaluated in OPG and CBCT. The number of teeth with complete root development, with apical ends of the roots completely closed (N_0) was calculated. Teeth with incomplete root development, therefore with open apices, were considered. For teeth with one root, the distance (A_i , $i=1, \dots, 5$) between the inner sides of the open apex was measured, and for teeth with two roots (A_i , $i=6, 7$), the sum of the distances between the inner sides of two apices was calculated. Then, A_i measurements were standardized by dividing them by the tooth length L_i : $x_i = A_i/L_i$, $i = 1, \dots, 7$. Dental maturity was determined using the normalized measurements ($x_i = A_i/L_i$, $i=1, \dots, 7$), the sum of normalized open apices (s) and the number with root development complete (N_0). Age was estimated using the linear regression formula for the Indian population $\text{Age} = 9.402 - 0.879 C + 0.663 N_0 - 0.711 s - 0.106 s N_0$, where C is a variable, 0 for central or north India and 1 for south.

RESULTS & DISCUSSION:

TABLE NO. 1 DESCRIPTIVE ANALYSIS OF DENTAL AGE ESTIMATED BY OPG & CBCT AMONG STUDY SAMPLES

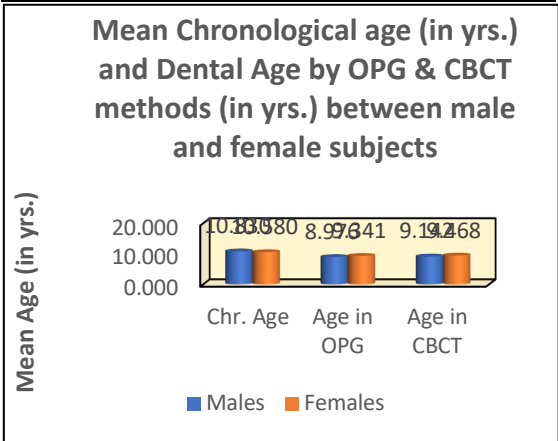
Table no. 1 Descriptive analysis of Dental Age estimated by OPG & CBCT among study samples						
Parameters	N	Mean	SD	Median	Min	Max
Age in OPG	100	9.166	1.995	9.60	5.9	12.47
Age in CBCT	100	9.312	2.029	9.70	6.1	13.68

Descriptive analysis revealed that both modalities provided comparable estimations of dental age, with CBCT consistently yielding slightly higher values than OPG. The range of values indicated that CBCT captured a broader spread of dental age compared to OPG. (Table 1)

The reliability and reproducibility of Cone Beam Computed Tomography (CBCT) are high, as it is able to produce multi-planar reformatted images, giving a two-dimensional view in the axial, coronal, and sagittal planes. This is advantageous in minimizing difficulties associated with orientation errors and overlapping structures as compared to OPG⁹.

TABLE NO. 2 COMPARISON OF MEAN CHRONOLOGICAL AGE (IN YRS.) AND DENTAL AGE BY OPG & CBCT METHODS (IN YRS.) BETWEEN MALE AND FEMALE SUBJECTS USING MANN WHITNEY TEST

Parameter	Gender	N	Mean	SD	Mean Diff	p-value
Chr. Age	Males	48	10.830	2.444	0.250	0.64
	Females	52	10.580	2.531		
Age in OPG	Males	48	8.976	1.884	-	0.41
	Females	52	9.341	2.095		
Age in CBCT	Males	48	9.142	1.869	-	0.52
	Females	52	9.468	2.174		



GRAPH 1: MEAN CHRONOLOGICAL AGE (IN YRS.) AND DENTAL AGE BY OPG & CBCT METHODS (IN YRS.) BETWEEN MALE AND FEMALE SUBJECTS

The mean difference of -0.365 years indicated that females had slightly higher dental age values than males by OPG, but this difference was not statistically significant ($p=0.41$). The mean

difference of -0.326 years suggested marginally higher values in females compared to males by CBCT; however, this difference was not statistically significant ($p=0.52$). (Table 2, Graph 1)

Gender-based comparisons demonstrated minimal alterations between males and females in both chronological and dental age estimations. These differences were small and did not indicate any consistent pattern favouring one gender over the other.

The slightly higher values obtained for dental age in females than in males could be attributed to the inherent sexual dimorphism, where there are earlier developmental milestones and more advanced development in females than in males. This is seen in the age range for middle childhood and early adolescence, as the closure rate for the formation of permanent teeth is slightly earlier for girls than for boys¹⁰.

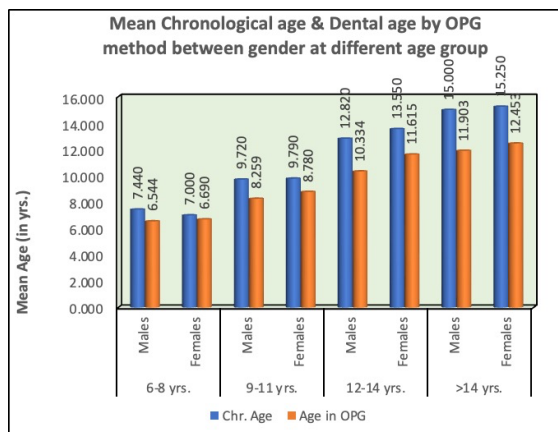
TABLE 3: COMPARISON OF MEAN CHRONOLOGICAL AGE AND DENTAL AGE BY OPG AND CBCT METHODS BETWEEN GENDER AT DIFFERENT AGE GROUPS USING WILCOXON SIGNED-RANK TEST

Age group	Gender	N	Chr. Age (in yrs.)	Dental Age (in yrs.)	Mean ± SD	p-value	Dental Age (in yrs.)	Mean ± SD	p-value
6-8 years	Male	9	7.44	6.54	0.89 ± 0.41	0.01*	6.71	0.70 ± 0.18	0.01*

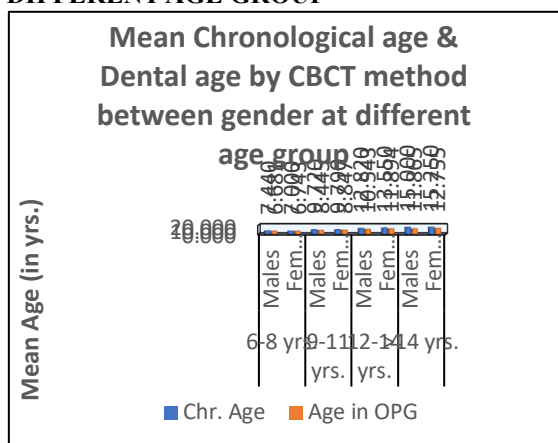
Chronological and Dental Age Estimation by Measurements of Open Apices using CBCT and OPG in Paediatric Population (7 to 15 years) – A Digital Comparative Study

rs			0.52 7	0. 35 8	9 6		± 0. 2 8 3	5 9	
	Fe m a l e s	8	7.00 0 ± 0.53 5	6. 69 0 ± 0. 43 9	0. 3 1 0	0. 21 0	6. 7 4 3 ± 0. 3 5 0	0. 2 5 8	0. 33
9 – 1 1 y r s	M a l e s	1 8	9.72 0 ± 0.66 9	8. 25 9 ± 1. 34 0	1. 4 6 1	<0 .0 01 *	8. 4 4 5 ± 1. 3 2 0	1. 2 7 5	<0 .0 01 *
	Fe m a l e s	2 9	9.79 0 ± 0.72 6	8. 78 0 ± 1. 37 7	1. 0 1 0	<0 .0 01 *	8. 8 4 7 ± 1. 3 7 8	0. 9 4 3	<0 .0 01 *
1 2 – 1 4 y	M a l e s	1 7	12.8 20 ± 0.72 8	10 .3 34 ± 0.	2. 4 8 6	<0 .0 01 *	1 0. 5 4 3 ±	2. 2 7 7	<0 .0 01 *

rs				61 2			0. 6 0 8		
	Fe m a l e s	1 1	13.5 50 ± 0.68 8	11 .6 15 ± 0. 92 0	1. 9 3 5	0. 00 3*	1 1. 8 9 4 ± 0. 8 5 0	1. 6 5 6	0. 00 3*
> 1 4 y r s	M a l e s	4	15.0 00 ± 0.00 0	11 .9 03 ± 0. 66 1	3. 0 9 8	<0 .0 01 *	1 1. 8 6 5 ± 0. 7 3 4	3. 1 3 5	<0 .0 01 *
	Fe m a l e s	4	15.2 50 ± 0.50 0	12 .4 52 † ± —	2. 7 9 8	<0 .0 01 *	1 2. 7 5 5 ± 0. 6 1 7	2. 4 9 5	<0 .0 01 *



GRAPH 2: COMPARISON OF MEAN CHRONOLOGICAL AGE & DENTAL AGE BY OPG METHOD BETWEEN GENDER AT DIFFERENT AGE GROUP



GRAPH 3: COMPARISON OF MEAN CHRONOLOGICAL AGE & DENTAL AGE BY CBCT METHOD BETWEEN GENDER AT DIFFERENT AGE

In the 6–8-year age group, males showed a mean difference of 0.896 years, which was statistically significant ($p = 0.01$), whereas females showed a mean difference of 0.310 years, which was not statistically significant ($p = 0.21$). (Table 3, Graph 2) In the 6–8-year age group, males showed a mean difference of 0.759 years, which was statistically significant ($p = 0.01$), whereas females demonstrated a mean difference of 0.258 years that was not statistically significant ($p = 0.33$). (Table 3, Graph 3)

Ethnic differences in the rate of tooth and root development play an important role in the accuracy of the method of estimation of the age of the individual¹¹. There is evidence that the pattern of dental maturation differs among various ethnic groups due to genetic and environmental factors. This might influence the accuracy of the method of estimation of the age of the individual by reducing the dental age compared to the chronological age¹². In the 9–11-year age group, the mean differences were 1.461 years in males and 1.010 years in

females, with both values being statistically significant ($p < 0.001$).

In the 9–11-year age group, the mean differences were 1.275 years in males and 0.943 years in females, with both values being statistically significant ($p < 0.001$).

Delayed maturation of the teeth may be seen in children who have constitutional growth delay or poor nutritional status. In such conditions, overall somatic growth is slower, and this delay can also affect tooth mineralization, root formation, and apex closure¹³. Poor nutrition among children will lead to delayed development of the teeth. Therefore, the development of the teeth will be slow. This will be reflected in the apex closure that is considered in the estimation of the dental age^{14,15}. This will lead to an underestimate of the dental age compared to the chronological age of the children.

For the 12–14-year age group, the mean differences increased to 2.486 years in males and 1.935 years in females, and both were statistically significant ($p < 0.001$).

For the 12–14-year age group, the mean differences increased to 2.277 years in males and 1.656 years in females, and both were statistically significant ($p < 0.001$).

Individual differences in the growth rates may cause the dental age to be less than the chronological age. Asynchronous growth rates due to various factors, including genetic and environmental factors, may cause the chronological and dental ages of children to be different¹⁶. Children who have slow rates of somatic growth may display radiographic evidence of incomplete root development and wider open apices compared to children who have higher rates of growth¹⁷. This occurs because the process of tooth mineralization and apex closure is related to the rates of systemic growth. In certain cases, dental development may progress at a rate that differs from skeletal maturation, leading to discrepancies between dental age and chronological age¹⁸.

Among subjects older than 14 years, the mean differences further rose to 3.098 years in males and 2.798 years in females, with both showing high statistical significance ($p < 0.001$).

Among subjects older than 14 years, the mean differences further rose to 3.135 years in males and 2.495 years in females, with both showing high statistical significance ($p < 0.001$).

Individual genetic variations in odontogenesis-associated genes, such as those related to enamel formation (e.g., AMELX) or dentin mineralization (e.g., DSPP), can affect the rate of dental maturation^{19,20}. This can result in lower estimated age compared to chronological age based on methods such as the Cameriere open apex formula⁶. The polymorphisms can affect the rate of apex closure, thereby increasing the normalized open apex widths ('s' values) that underestimate age predictions^{21,22}.

Overall, across all age groups, dental age estimated by OPG consistently showed lower values compared to chronological age. The differences were statistically significant in most groups, with the magnitude of discrepancy increasing with age. Overall, across all age groups, dental age estimated by CBCT consistently showed lower values compared to chronological age. The differences were statistically significant in most groups, with the magnitude of discrepancy increasing with age.

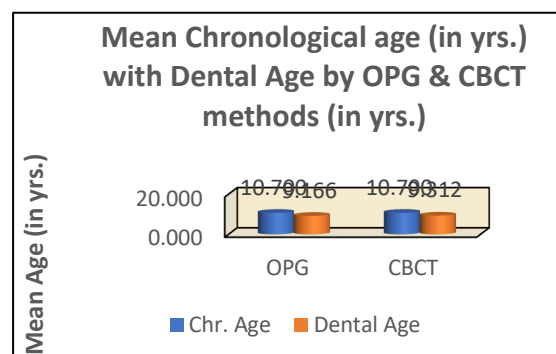
One reason for the age underestimation represents the difficulty in evaluating the small apex opening, which is almost closed/closed in older groups ^{22,23}.

Differences in interpretation of root development stages or open apices between observers may contribute to variation in estimated dental age due to subjective assessment of radiographic features like translucency or closure completeness. Intra-observer reliability improves with training and calibration, yet persistent inter-observer errors necessitate double-reading protocols in forensic odontology.

TABLE 4: COMPARISON OF MEAN CHRONOLOGICAL AGE (IN YRS.) WITH DENTAL AGE BY OPG & CBCT METHODS (IN YRS.) USING WILCOXON SIGNED RANK TEST

Method	Parameter	N	Mean	SD	Mean Diff	p-value
OPG	Chr. Age	100	10.700	2.480	1.534	<0.001*
	Dental Age	100	9.166	1.995		
CBCT	Chr. Age	100	10.700	2.480	1.388	<0.001*
	Dental Age	100	9.312	2.029		

* - Statistically Significant



GRAPH 4: COMPARISON OF MEAN CHRONOLOGICAL AGE (IN YRS.) WITH DENTAL AGE BY OPG & CBCT METHODS (IN YRS.)

When chronological age was compared with dental age across the entire sample, both OPG and CBCT consistently underestimated dental age. The differences between chronological and dental age were evident across all groups, with CBCT showing closer approximation to chronological age than OPG. (Table 4, Graph 4)

CBCT due to its three-dimensional imaging, minimizes distortions inherent in OPG's two-dimensional projection. CBCT eliminates superimposition of anatomical structures, offering precise measurement of open apices, root lengths, and pulp volumes unlike OPG, where elongation, foreshortening, or magnification skews distances from cemento-enamel junction to apex ^{24,25}. This leads to greater accuracy in the measurement of open apices and allows a closer approximation of dental age estimation using CBCT compared to OPG ²⁶.

TABLE NO. 5 SPEARMAN'S RANK CORRELATION TO ASSESS THE RELATIONSHIP BETWEEN CHRONOLOGICAL AGE AND DENTAL AGE ESTIMATION METHODS AMONG STUDY SAMPLES

Parameter	Dental Age by OPG			Dental Age by CBCT		
	N	rho	p-value	N	rho	p-value
Chr. Age	100	0.91	<0.001*	100	0.91	<0.001*

* - Statistically Significant

Spearman's Rank Correlation analysis highlighted strong and consistent relationships. Chronological age showed a very strong positive correlation with dental age estimated by both OPG and CBCT, indicating that as chronological age increased, dental age also increased proportionately. (Table 5) Dental development follows a predictable timeline in accordance with genetic and hormonal factors, where root apex closure and pulp chamber narrowing occur in a linear fashion in accordance with chronological age ²⁷. This occurs

proportionally as age progresses, as a result of consistent physiological processes such as those mediated by odontoblasts in dentin deposition and those involved in mineralization, which are consistent in healthy individuals²⁸. Genetic factors are responsible for a consistent sequence of events in dental development, from crown formation to root completion, with minimal interruption from environmental factors in non-pathological individuals²⁹. Hormonal regulation, particularly during growth phases, synchronizes these processes across populations, ensuring radiographic markers reliably mirror time elapsed since tooth formation began³⁰.

TABLE NO. 6 SPEARMAN'S RANK CORRELATION TO ASSESS THE RELATIONSHIP BETWEEN CHRONOLOGICAL AGE AND DENTAL AGE ESTIMATION METHODS BASED ON THE GENDER

Samples	Dental Age by OPG			Dental Age by CBCT		
	N	rho	p-value	N	rho	p-value
Males	4	0.9	<0.001*	4	0.8	<0.001*
Females	5	0.9	<0.001*	5	0.9	<0.001*

* - Statistically Significant

Overall, both OPG and CBCT methods demonstrated very strong correlations with chronological age across genders, with CBCT showing slightly higher correlation values in females (r-0.92) compared to males (r-0.89). These findings indicated that dental age estimation by both modalities reliably reflected chronological age, irrespective of gender. (Table no. 6)

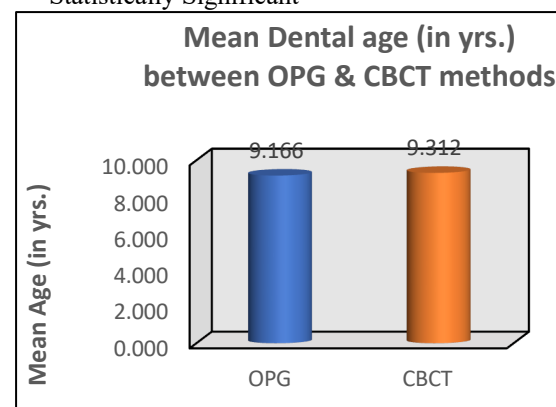
Sexual dimorphism significantly influences dental development in females, with girls demonstrating accelerated root maturation in early stages compared to males³¹. This is evident in mandibular second premolars and canines, where apex closure occurs 0.4-0.8 years earlier in girls, enhancing the precision of age estimation using these teeth³². Hormonal factors, such as elevated oestrogen levels during puberty, drive this faster odontogenesis in females, leading to advanced mineralization and root completion^{33,34}. Consequently, CBCT's detailed 3D imaging captures these subtle dimorphic differences more reliably than OPG³⁵, contributing to slightly higher correlation coefficients in females.

TABLE NO. 7 COMPARISON OF MEAN DENTAL AGE (IN YRS.) BETWEEN OPG &

CBCT METHODS USING WILCOXON SIGNED RANK TEST

Parameter	Method	N	Mean	SD	Mean Diff	p-value
Age (in yrs.)	OP	1	9.1	1.9	-0.146	<0.001*
	G	0	66	95		
	CB	1	9.3	2.0		
	CT	0	12	29		

* - Statistically Significant



GRAPH 5: COMPARISON OF MEAN DENTAL AGE (IN YRS.) BETWEEN OPG & CBCT METHODS

Findings indicated that although both OPG and CBCT methods provided comparable estimations of dental age, CBCT (9.312 ± 2.029 years) consistently yielded slightly higher mean values than OPG (9.166 ± 1.995 years). The statistical significance of the difference suggested that CBCT demonstrated marginally greater accuracy in dental age estimation compared to OPG. (Table 7, Graph 5)

Though OPG provides a simple 2D view, it is limited by inherent disadvantages like horizontal distortion, vertical magnification, positioning errors, geometrical distortion, exaggeration of images, and overlapping structures like ghost shadows of contralateral structures^{36,37}. On the other hand, CBCT helps overcome these disadvantages with its true 3D multi-planar navigation, allowing for exact and undistorted visualization of dental morphology without any superimposition, as seen in panoramic or intraoral radiographs²⁶. This helps in more accurate dental age estimation, especially in adults, with a more quantitative assessment of pulp/tooth volume ratios and secondary dentin formation with high reproducibility³⁸.

TABLE NO. 8 SPEARMAN'S RANK CORRELATION TO ASSESS THE RELATIONSHIP BETWEEN DENTAL AGE

BY OPG & CBCT METHODS AMONG STUDY SAMPLES

Samples	Parameter	Dental Age by CBCT		
		N	rho	p-value
Overall	Dental Age by OPG	100	0.97	<0.001*
Males	Dental Age by OPG	48	0.95	<0.001*
Females	Dental Age by OPG	52	0.97	<0.001*

* - Statistically Significant

When dental age estimated by OPG was compared directly with dental age estimated by CBCT, both methods demonstrated very strong agreement. This consistency was observed in the overall sample as well as within male and female groups, confirming that both modalities were highly aligned in their estimations. (Table 8)

Dental age estimated by both OPG and CBCT shows a positive correlation, but CBCT has better reliability compared to OPG because it provides true 3D, near 1:1, sub-millimetre-accurate measurements with minimal magnification, distortion, and superimposition of structures^{39,40}. This allows clearer visualization of root morphology leading to higher accuracy and better inter- and intra-observer agreement than 2D panoramic images^{41,42}.

Therefore, OPG could be used for the initial assessment and screening, and CBCT could be used in cases where more accuracy is needed.

CONCLUSION

Human identification involves establishing the individuality of a living or deceased person, with age estimation being an important component, particularly in children and adolescents, where dental development provides a reliable indicator of chronological age. Radiography plays a vital role in forensic dentistry, and although panoramic radiography (OPG) has been traditionally used, CBCT offers additional three-dimensional information. The present study evaluated 100 children aged 7–15 years using the Indian-specific Cameriere formula based on open-apex measurements of seven left permanent mandibular teeth, excluding third molars, and compared dental age estimated from OPG and CBCT with chronological age. Both modalities showed strong positive correlations with chronological age and consistently underestimated dental age, with greater discrepancies observed in older age groups. Gender-wise comparisons showed minimal differences, while OPG and CBCT demonstrated strong agreement with each other. CBCT provided slightly

closer and more precise age estimates, attributable to its higher resolution and three-dimensional visualization, whereas OPG remains advantageous for routine screening because of its simplicity, accessibility, and lower radiation exposure. Overall, both modalities are effective for dental age estimation, with CBCT offering an incremental advantage in accuracy and precision, particularly in forensic and clinical applications.

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