Original Research Paper

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Skeletal Maturity Assessment Using Cone Beam Computed Tomography

Abstract:

Aim And Objectives: The aim of the present study was to assess and compare skeletal maturity with use of Cone Beam Computed Tomography, Lateral Cephalography and middle phalanx of third finger.

Objectives: 1. To compare skeletal maturity between Cone Beam Computed Tomography and Middle phalanx of third finger.
2. To compare skeletal maturity between Lateral Cephalography and Middle phalanx of third finger.
3. To compare skeletal maturity between Cone Beam Computed Tomography and Lateral Cephalography.

Materials and methods: Skeletal maturity of patient was assessed by three radiographic methods including hand wrist radiograph from middle phalanx of hand (MPS), cervical vertebrae maturation(CVM) from lateral cephalograms (cephalo-CVMI) and sagittal images of Cone Beam ComputedTomography (CBCT-CVMI). The Spearman correlation coefficient was used for statistical analysis.

Results: We observed significant correlation between these radiographic methods of skeletal maturity assessment. The Spearman correlation coefficient value between MPS and CBCT-CVMI was 0.93, p=0.01, cephalo-CVMI and CBCT-CVMI was 0.98, p=0.01and MPS and Cephalo – CVMI was 0.91, p=0.01

Conclusion: Skeletal maturity can be assessed in CBCT or lateral cephalogram reliably along with their primary indications, eliminating hand wrist radiograph for skeletal maturity assessment. This will reduce radiation exposure and cost of treatment to patient.

Key-words: Skeletal maturity assessment, Cone Beam computed tomography CBCT, Cervical vertebrae maturation, middle phalanx method.

Introduction:

The identification of optimal timing of skeletal maturity has been the holy grail of radiological research. Assessment of developmental stage and somatic maturity is important for diagnosis and treatment planning in field of Medicine and Dentistry. Every individual matures according to their own biological age or "biological clock". In order to determine the most reliable indicator of maturity different researchers had suggested various methods for skeletal maturity assessment. These include height and weight, chronological age, onset of puberty or sexual maturation, frontal sinus maturation, hand-wrist maturity, cervical vertebrae maturation(CVM); dental eruption and dental calcification stages and biomarkers like dehydroepiandrosterone, Serum Parathyroid Hormone-related Protein.(PTHrP), Serum Insulin like Growth Factor -1(IGF-1), Alkaline phosphatise etc. [1]

Because of significant individual variation, chronological age cannot be considered as reliable indicator of maturity status.[2] Increase in height can be a indicator of the peak in growth but this requires longitudinal examinations over a period of time. Even body weight is a poor indicator of maturity as in previous

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studies[3-4] there was lack of any significant relationship between body weight and skeletal maturity. Estimation of present maturational status based on sexual maturity involves the examination of secondary sexual characters. This method requires physical examination and limited to period till completion of puberty.[3-4]

For living individual radiographical methods for dental maturity assessment are commonly used because they are simple, reproducible, non-invasive. Unlike histological or biochemical evaluation of extracted teeth, radiographic method allows evaluation of maturity in-vivo. Radiographs are valuable tools for reproducible and longitudinal evaluation. Various sequential indicators which can be used for radiographic assessment of skeletal maturity studied by Schour and Masseler (1941), Nolla (1960), Moorees fanning and Hunt (1963), Kraus and Jordan (1965) and Demirjian et al (1973) [5]

Some bones in body demonstrate organized events of ossification, thus degree of ossification in these bones determines skeletal maturation. These phases of ossification can be seen radiographically. Out of various bones, hand-wrist and cervical vertebrae are explored extensively as indicators of maturity.[1] The gold standard radiographic method of evaluating skeletal maturity has been a hand-wrist radiograph. This requires an additional exposure of patient to ionising radiation.[6]

In this current era of radiation exposure awareness, we can take a radiographic image of only MP3 instead of complete hand and wrist radiograph for growth assessment, as it is a simple method of skeletal maturity assessment which can be done using an Intraoral Periapical (IOPA) film and a standard dental x-ray machine. The results of the study by Madhu S et al (2003) [7]showed that this method is highly reliable.

Skeletal maturity can also be assessed on the basis of shape changes and depth of inferior concavity of cervical vertebrae which is found to be reliable method as hand wrist method. [8 - 12]

Cone Beam Computed Tomography (CBCT) was introduced in Europe in 1990s and approved by the Food and Drug Administration (FDA) for use in the United States in 2001 has become popular advancement in the field of radiology.[13] It is integrated into the dental practice very rapidly due to its simple-user friendly design and compact size, low ionizing radiation exposure compared to medical Computed Tomography(CT), advantage of collimation and low cost to patient. Like medical CT, it provides 3- dimensional (3D) examination of maxillofacial region with limited distortion of image. In these machines collimation is possible ie selection of Field Of View (FOV) to area of interest which reduces size of irradiated site. CBCT has an added advantage of superior image accuracy as they provide isotropic voxels i.e. equal in all three proportions as compared to anisotropic voxels present in conventional CT and has rapid scan time as only single rotation is required which has secondary advantage in plummeting the artefacts owing to patient movement. It shows cervical vertebrae in three dimensions including sagittal image for skeletal maturity assessment by conventional methods. This prevents additional exposure of patient when CBCT is required for diagnostic purpose.[14] CBCT can also provide accurate quantitative assessment of cervical vertebrae in 3 planes, including axial plane for Axial Cervical Vertebral (ACV) maturation method. This could reduce observational examiner errors in radiographic interpretations.[15]

Considering prevalent use of CBCT we propose a study to compare skeletal maturity on sagittal CBCT images of cervical vertebrae, lateral cephalogram and middle phalanx method, which would eliminate additional ionizing radiation exposure to patient for skeletal maturity assessment.

Materials and Methods:

The present study was conducted in Department of Oral Medicine and Radiology, Rishiraj college of Dental Sciences and Research Centre, Bhopal (M.P.) in association with Diya Dental imaging Bhopal, (M.P.) after approval from the institutional ethical committee. Written informed consent was obtained from each patients or parent (sample 18 years below).

Patient reported to the department of Oral Medicine and Radiology with age between 8 to 20 years who require hand wrist, lateral cephaogram and CBCT as additional investigation for orthodontic purpose were selected.

Patient presenting with congenital or acquired malformation affecting middle finger and cervical vertebrae were excluded from study.

To record hand wrist radiograph of patient, extraoral machine (Allengers – 100 mA X Ray machine, Allengers, Chandigarh, India) in Rishiraj College of Dental Sciences and Research Centre, Bhopal with exposure parameters : Potential difference: 50 kV ; Tube Current: 50mA and Exposure timing 0.8 sec was used. To record lateral cephalogram of patient orthopantomogram with lateral cephalogram machine was used (Satelec X-mind Pano D+ digital panoramic and Cephalometric X – Ray unit, United Kingdom) in Rishiraj college of dental sciences and research centre, Bhopal with exposure parameters : Potential difference 60-85 kV ; Tube Current 10-11 mA ; Exposure timing 17 sec and Magnification factor: 1.1. To record CBCT data of cervical vertebrae, CBCT machine (Dentsply Sirona Orthophos SL CBCT machine, Germany) in Diya dental imaging, Bhopal, with exposure parameters Peak voltage: 80 kVp; Tube current: 12mA ; Exposure time: 14 sec and FOV 11*10 cm was used.

After explaining radiographic procedures briefly to patient, written consent were taken from patients over 18 years of age or from the parents for patients below 18 years of age.

For Hand wrist radiography, under standard dark room conditions, 8 X 10 inch radiographic film was loaded in 24 X 30 cm cassette with intensifying screens. Patient was asked to remove metallic objects from hand and wrist like rings, watch or bracelets. Patient was seated at the end of the table comfortably to ensure maximum radiation protection sparing lower limbs and gonads away from primary beam. Forearm was pronated on the table with palmer surface of hand in close approximation with the cassette. Fingers were separated and extended but relaxed to ensure that they remain in contact with the cassette. Beam was collimated within margins of cassette. Vertical central beam was centred over head of the third metacarpal.

For lateral cephalography, patient was asked to remove metallic objects from neck and head. Lead apron without a lead collar was provided to prevent superimposition over cervical vertebrae. The right side of the patient's head was positioned against the digital sensor of extended cephalometric arm of OPG machine. The mid sagittal plane was perpendicular to the floor and parallel to the sensor. The patient's head was stabilized with the help of the ear rods, nasion positioner and the orbital rod. The patient was asked to keep the teeth in occlusion during entire procedure. The central beam directed perpendicular to the midsagittal plane of the patient and the plane of the image receptor. It was centered over the external auditory meatus.

For CBCT imaging, patient facial topographic reference planes were used such that mid sagittal plane was perpendicular to floor and Frankfort horizontal plane parallel to floor. Patient was asked to bite the bite block. FOV was selected as 11 X 10 cm^2. Patient's head was stabilized in machine to prevent head movement.

For CBCT images acquisition on computer a medical imaging software 3Diagnosys® (3DIEMME bioimaging technologies, Italy). Sagittal image was selected such that the midsagittal plane becomes perpendicular to the floor, running through the intermaxiilary suture and anterior nasal spine. CVMI was evaluated on sagittal slice. In case of head tilt of the patient, in CBCT image it was corrected on the computer such that the midsagittal plane is perpendicular and running through the intermaxiilary suture and anterior nasal spine. (Figure 1)

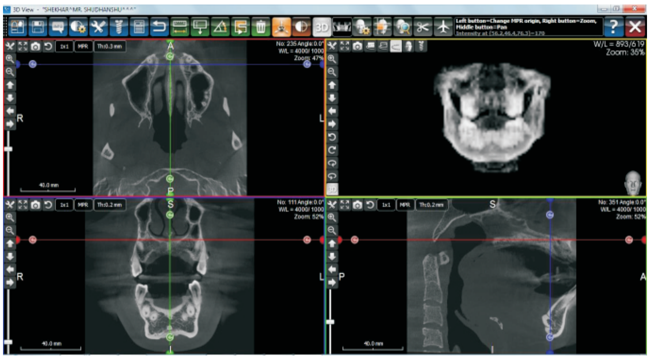

Figure 1: CBCT image acquisition in a software for evaluation of CVMI.

For skeletal maturity assessment from middle phalanx of hand (MPS) Perinetti et al method [16] was used. (Table 1)

Stage (MPS)	Description
1	x Epiphysis is narrower than the metaphysis x When epiphysis is as wide as metaphysic but lateral borders are tapered and rounded x Epiphysis and metaphysis are not fused
2	x Epiphysis is as wide as the metaphysis with increasing thickness at sides and showing clear line of demarcation at right angle x With or without lateral steps on upper contour x More mature side is used to assign the stage in case of asymmetry between the two sides
3	x Epiphysis is either as wide as metaphysis or wider with lateral sides x Showing an initial capping towards the metaphysis. x More mature side is used to assign the stage in case of asymmetry between the two side x Epiphysis and metaphysis are not fused
4	x Epiphysis begins to fuse with metaphysis x Contour of former is still recognizable x Sides of epiphysis form obtuse angle to distal border x Capping may still detectable
5	x Epiphysis is fused with metaphysis completely

Table 1:Showing Perinetti et al method. (MPS: Stage of skeletal maturity using Perinetti et al method) [16]

For assessment of skeletal maturity from cervical vertebrae (Cephalo - CVMI) on lateral cephalogram and on sagittal images of CBCT (CBCT - CVMI) Hassel and Farman method [17] was applied.

(Table 2)

CVMI	Stage	Description
1	Initiation	x C2, C3, and C4 inferior vertebral body borders are flat x Superior vertebral borders are tapered posterior to anterior.
2	Acceleration	x Concavities developing in lower borders of C2 and C3 x Lower border of C4 vertebral body is flat x C3 and C4 are more rectangular in shape
3	Transition	x Moderate amount of adolescent growth expected x Distinct concavities in lower borders of C2 and C3 x C4 developing concavity in lower border of body x C3 and C4are rectangular in shape
4	Deceleration	x Distinct concavities in lower borders of C2, C3, and C4 x C3 and CA are nearly square in shape
5	Maturation	x Accentuated concavities of inferior vertebral body borders of C2, C3, and C4 x C3 and C4 are square in shape
6	Completion	x Deep concavities are present for inferior vertebral body borders of C2, C3, and C4 x C3 and C4 heights are greater than widths

Table 2: Showing Hassel and Farman method. (CVMI : Stage of Cervical vertebrae maturity)[17]

All data collected was assessed by 2 observers (Oral and Maxillofacial Radiologist). They were double blinded during entire study. Data obtained was tabulated. Interobserver reliability assessment was done be using kappa statistics. (Table 3) Statistical Package for the Social Sciences (SPSS) software (version 9.01; SPSS, Chicago, Illinois) was used for statistical analysis. To assess the relationship between CBCT - CVMI and Cephalo - CVMI and between CBCT - CVMI and MPS, Spearman rank correlation coefficient test was used.

SNO	METHOD	INTEROBSERVER VARIABILITY	INFERENCE
1	Middle phalanx of third finger	0.987	Almost perfect agreement
2	Lateral cephalogram	0.952	Almost perfect agreement
3	CBCT	0.939	Almost perfect agreement

Table 3: Showing interobserver variability between two observers and inference according to Landis and Koch (1977). [18]

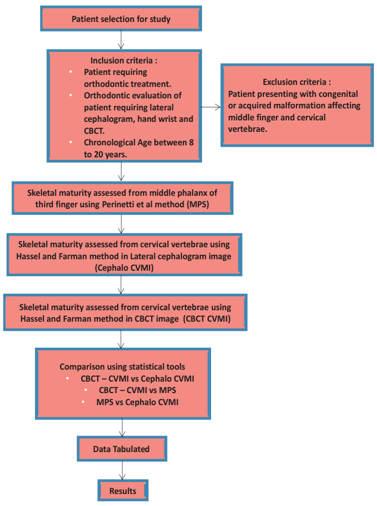

Figure 2: Flowchart describing in brief methodology of study.

Results:

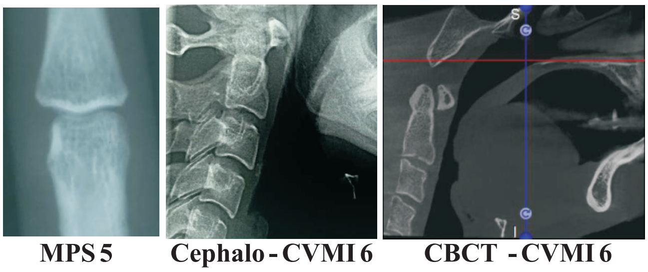

Figure 3: Sample case 1: Stages of skeletal maturity seen in sectional images of hand wrist radiograph(MPS), Lateral cephalogram(Cephalo- CVMI) and CBCT (CBCT - CVMI).

First on comparison of skeletal maturity assessed with lateral cephalogram method and CBCT method using Spearman correlation coefficient test, there was a significant positive correlation between cephalo-CVMI and CBCT-CVMI with Spearman's coefficient (r^2) being 0.98, p=0.01.

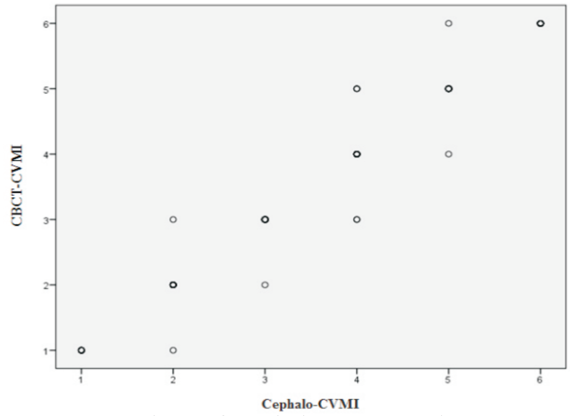

Figure 4: Comparison of Cephalo-CVMI and CBCT-CVMI, among the study population.

Using Spearman correlation coefficient test, comparison of skeletal maturity assessed with CBCT method and middle phalanx method was significant positive with Spearman's coefficient (r^2) being 0.93, p=0.01.

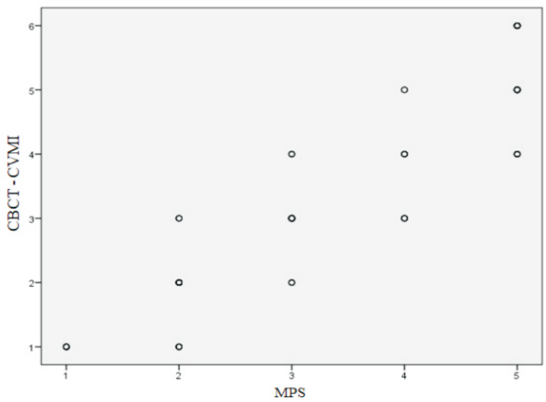

Figure 5: Comparison of MPS and CBCT-CVMI, among the study population.

On Comparison of skeletal maturity assessed with middle phalanx method and lateral cephalogram method, there was a significant positive correlation between the MPS method and Cephalo – CVMI method with Spearman's coefficient (r^2) being 0.91, p=0.01.

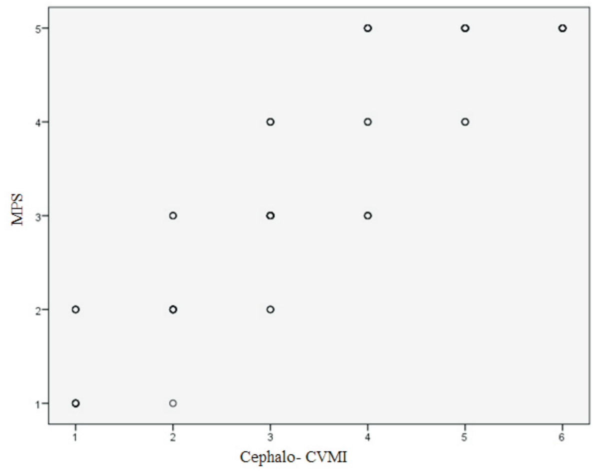

Figure 6: Comparison of MPS and Cephalo -CVMI, among the study population. Skeletal maturation index (MPS) ; Cervical vertebrae maturation index assessed with the use of lateral cephalogram (*Cephalo* – CVMI).

Discussion:

Present maturational status of a patient can affect diagnosis, treatment planning, goals and expected outcomes especially in orthodontic treatment (Table 4). Radiographic estimation of skeletal maturity also helps the clinician to correlate with clinical findings, enabling differentiation from normal, relatively advanced or retarded growth. [19] Estimation of present chronological age based on skeletal maturation is prevalent practice in Forensic Medicine, especially where age is unknown or fraudulent [20]

CVMI	Stage	Description	Correlation with growth phase
1	Initiation	x C2, C3, and C4 inferior vertebral body borders are flat x Superior vertebral borders are tapered posterior to anterior.	Very significant amount of adolescent growth expected
2	Acceleration	x Concavities developing in lower borders of C2 and C3 x Lower border of C4 vertebral body is flat	Significant amount of adolescent growth expected
		x C3 and C4 are more rectangular in shape	
3	Transition	x Moderate amount of adolescent growth expected x Distinct concavities in lower borders of C2 and C3 x C4 developing concavity in lower border of body x C3 and C4 are rectangular in shape	Moderate amount of adolescent growth expected
4	Deceleration	x Distinct concavities in lower borders of C2, C3, and C4 x C3 and CA are nearly square in shape	Small amount of adolescent growth expected
5	Maturation	Accentuated concavities of inferior vertebral body borders of C2, C3, and C4 C3 and C4 are square inshape	Insignificant amount of adolescent growth expected
6	Completion	x Deep concavities are present for inferior vertebral body borders of C2, C3, and C4 x C3 and C4 heights are greater than widths	Adolescent growth is completed

Table 4 Favourable CVMI stage(s) based on type of orthodontic treatment. [13, 21,22]

Since long time skeletal maturity is assessed using hand wrist radiograph which is considered as gold standard but this require an additional exposure to patient to ioning radiation solely for assessment of skeletal maturity. Skeletal maturity can be assessed with cervical vertebrae in lateral cephalogram or CBCT images as seen in study of Joshi et al (2012)[13], they conducted a study on 100 subjects and estimated skeletal maturity using hand wrist radiograph byFishman's (1982)[24] method (SMI) and cervical vertebral maturity on lateral cephalogram(cephalo-CVMI) and sagittal images of CBCT(CBCT-CVMI) using Hassel Farman method[17].On comparison between CBCT-CVMI and cephalo-CVMI Spearman correlation coefficient was 0.975 suggesting strong correlation between two methods which is similar to our study with Spearman correlation coefficient 0.98. When SMI was compared with CBCT- CVMI significant correlation was found between two methods (r^2= 0.964) which is similar to our study (r^2 = 0.93). Thus Joshi et al[13] concluded skeletal maturity assessment on CBCT is reliable method and CBCT can be used for this purpose, which is similar to our study.

In a study by Shim J (2012)[22] lateral cephalometric radiographs and sagittal images of CBCT scans were compared based on cervical vertebral maturation staging, he found Interclass Correlation Coefficent (ICC) of 0.16 which is non-significant unlike our study CBCT -CVMI and cephalo - CVMI was found to be significant (p = 0.01) .

When hand wrist method was compared with CBCT method by Byun B et al (2015) [25] significant correlation was found (p< 0.05) which is similar to our study (p = 0.01).

In a comparative study of Tekin A and Aydin K (2019)[26] on 105 subjects, they estimated skeletal maturity on hand wrist radiographs using "Digital Atlas of Skeletal Maturity" by Vicente Gilsanz and Osman Ratib[53] and for assessment of cervical maturity they used Hassel Farman method[22] for lateral cephalogram and CBCT sagittal images.They foundsignificant correlation between SMI and Cepahlo-CVMI, SMI and CBCT-CVMI and cephalo-CVMI and CBCT-CVMI each (p<0.05) similar to our study. Thus they concluded skeletal maturity assessment on CBCT is as reliable method as the evaluation on hand–wrist radiographs. The conclusion of this study is similar to our present study thus negating the use of extra hand–wrist radiograph.

In a study of Sánchez G et. al (2020)[27] where they estimated and compared the cervical vertebrae maturity in lateral cephalogram and sagittal images of CBCT, they found significant correlation between two methods and Spearman rank correlation coefficient with $p < 0.05$. They concluded orthodontists might use the CBCT scans as a valuable tool for CVM method estimation. The results are again similar to our study.

In the most recent study of Vyshyambath et al (2020)[28] compared cervical maturation stage using lateral cephalogram, CBCT and skeletal maturation using hand-wrist radiograph. They found that all three methods were reliable with p value 0.05 and thus concluded CVMI using lateral cephalogram and CBCT shows high reliability in prepubertal, pubertal, and post-pubertal male and female subjects. The skeletal maturity indicator using hand-wrist shows reliable tool for skeletal maturity. When the accuracy between the aids was compared, it revealed that CBCT is the most accurate diagnostic aid in assessing skeletal maturity indicator.

SNO	Study	Results for skeletal maturity assessment			Conclusion
		Hand wrist vs CBCT (p value)	Hand wrist vs Lateral cephalogram (p value)	Lateral cephalogram vs CBCT (p value)	
1	**Present study**	**0.01**	**0.01**	**0.01**	**Significant correlation**
2	Joshi et al (2012)[26]	< 0.0001	-	< 0.0001	Highly significant correlation
3	Byun B et al (2015)[29]	< 0.05	-	-	Significant correlation
4	Tekin A(2019)[34]	< 0.05	-	<0.05	Significant correlation
5	Sánchez G et. al (2020)[52]	-	-	<0.001	Highly significant correlation
6	Vyshyambath et al (2020)[28]	<0.05	<0.05	<0.05	Significant correlation

Table 5: Summary of results of studies on skeletal maturity assessment using CBCT showing comparison of their p values.

SNO	Study	Statistical Tool for correlation evaluation	Results for skeletal maturity assessment			Conclusion
			Hand wrist vs CBCT	Hand wrist vs Lateral cephalogram	Lateral cephalogram vs CBCT	
1	**Present study**	**Spearman rank correlation coefficient**	**0.93**	**0.91**	**0.98**	**Very high positive correlation**
2	Joshiet al (2012)[26]	Spearman rank correlation coefficient	0.961	-	0.975	Very high positive correlation
3	Shim J (2012)[27]	Interclass correlation coefficient	-	-	0.16	Not consistent
4	Byun B et al (2015)[29]	Pearson correlation coefficient	78.6%	-	-	High positive correlation
5	Tekin A(2019)[34]	Spearman rank correlation coefficient	0.706	-	0.875	High positive correlation
6	Sánchez G et. al (2020)[52]	Spearman rank correlation coefficient	-	-	0.976	Very high positive correlation

Table 6: Showing comparison between statistical tools used in studies for assessment of skeletal maturity assessment using CBCT.

Thus if a patient requires CBCT large FOV scanning protocol for diagnosis and treatment planning, skeletal maturity can be assessed by observing morphological changes in the cervical vertebrae. Here it should be noted that CBCT should not be used solely for the purpose of skeletal maturity assessment instead, when used as an investigating tool skeletal maturity can also be assessed reliably avoiding any additional radiograph.

Conclusion:

The current study was conducted to assess and compare skeletal maturity using hand wrist radiograph, lateral cephalogram and CBCT. Based on results of this study we drawn following conclusions:

1. When skeletal maturity assessed in hand wrist radiograph and lateral cephalogram, on comparison between these two methods significant positive correlation was found, (Spearman's coefficient: 0.91) and (p: 0.01).
2. When skeletal maturity assessed in CBCT, on comparison with hand wrist radiograph significant positive correlation was found between these two methods (Spearman's coefficient: 0.93) and (p 0.01).
3. Similarly when skeletal maturity was compared between lateral cephalogram and CBCT, significant positive correlation was found between these two methods (Spearman's coefficient: 0.98) and (p 0.01).

Thus skeletal maturity can be assessed in lateral cephalogram or CBCT reliably along with their primary indications, eliminating hand wrist radiograph for skeletal maturity assessment. This will reduce radiation exposure and cost of treatment to patient.

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