Assessment of Cervical Vertebral Bone Mineral Density in Adolescents Undergoing Functional Appliance Treatment

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Abstract

Aim: The cervical vertebral maturation (CVM) method has proved to be effective to assess the adolescent growth peak in both body height and mandibular size. The aim of this study was to evaluate whether cone-beam computed tomography (CBCT) images can be used to detect the changes of cervical vertebral bone mineral density (BMD) distribution and whether these changes are associated with CVM changes and mandibular length.

Materials and methods: Samples were collected from the patients of age group between 9 years and 15 years of both sexes, who reported to the Department of Orthodontics and Dentofacial Orthopedics, RajaRajeswari Dental College and Hospital, Bengaluru. All the measurements were done on constructed CBCT three-dimensional images. Gray levels, which are equivalent to the BMD, were obtained for C2 and C3 vertebrae at pretreatment (T1) and six months after starting the treatment (T2). The vertebral variables [mean, standard deviation (SD)], CVM stages, and mandibular length between T1 and T2 were compared.

Results: Significant changes in the examined variables were detected during the observation period. The BMD values showed a positive correlation with mandibular length increments.

Conclusion: The CBCT is an effective tool to analyze the volumetric parameter of BMD in routine dentofacial orthopedics and the BMD distribution changed because of active bone remodeling during the maturation.

Clinical significance: This study proves that CBCT imaging can provide additional information about the growth status of a patient above and beyond that obtained from two-dimensional cephalometric radiographs. CBCT is an effective tool to analyze the volumetric parameter of BMD in routine dentofacial orthopedics with better accuracy and minimum distortion.

Keywords: Bone mineral density, Cervical vertebral maturation, Cone-beam computed tomography, Retrospective study.

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Introduction

The assessment of skeletal maturity status and knowledge about the amount of skeletal growth remaining is necessary during the treatment planning for growth-modification appliances.[1] The evaluation of skeletal age is essential to determine the best treatment timing of functional appliances and orthognathic surgery.[2] Various methods have been proposed for the assessment of skeletal maturity which includes peak height velocity, skeletal maturation of hand wrist, dental age, voice change in males, menarche, and cervical vertebral maturation (CVM). Among these, the CVM method has proved to be the most effective.

Growth modification therapy using functional appliances gives maximum response during the circumpubertal growth period. The rational treatment planning in class II skeletal discrepancies with mandibular deficiencies demands a reliable biologic indicator that can detect the pubertal spurt in mandibular growth.[3]

The shortcoming of the CVM method is that the different stages are determined based on the changes in the shape and size of cervical vertebrae on a cephalogram which is a two-dimensional diagnostic tool. Thus, the CVM method provides qualitative data based on the subjective assessment increasing the possibility of observer bias. Many clinical studies observed poor reliability and repeatability of the CVM method for skeletal maturity assessment. Accurate quantitative analytical methods that allow numeric comparisons between groups are more useful than qualitative methods that rely on individual interpretations.[4] The cone-beam computed tomography (CBCT) gives information about bone

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mineral density (BMD) which is based on the gray scales of the images obtained.[5] The gray level is the range of shades of gray in the pixels. The shades of gray are caused due to the X-ray attenuation coefficient due to variations in tissue density. It was observed that the changes in the gray level and thereby the BMD changes correspond to the changes in various physiological events of bone development during the growth.[1]

So, in the present study, CBCT scan is used to assess the changes in cervical vertebral BMD in adolescents undergoing functional appliance therapy and to compare these changes with CVM stages and changes in mandibular length.
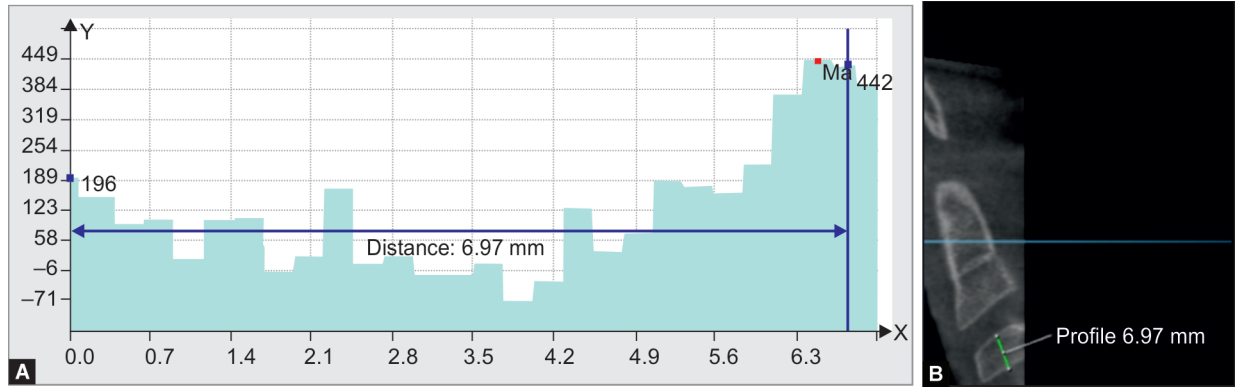
Figs 1A and B: Profile of gray-level values of C3 from CBCT
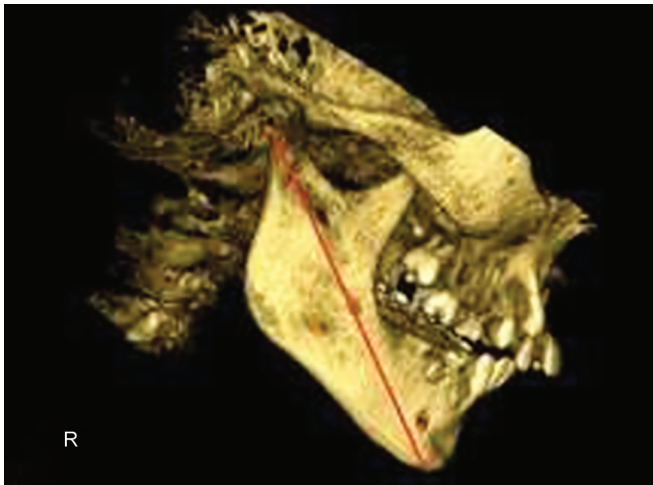
Fig. 2: Length of mandible distance from condylion to gnathion

MATERIALS AND METHODS

The adolescent patients of age group 9–15 years, of both sexes who received functional appliance therapy in the Department of Orthodontics and Dentofacial Orthopedics, RajaRajeswari Dental College and Hospital, Bengaluru, were selected for the study. The patients with craniofacial anomalies, facial asymmetries, orthognathic surgery, rapid maxillary expansion, and extractions were excluded from the study. Twenty three-dimentional CBCT images from 10 subjects were obtained at pretreatment (TI) and six months from the start of the treatment (T2). One pretreatment hand wrist radiograph was obtained from each patient to assess the growth status. The subjects were explained about the type of the study and consent was obtained from them regarding the same.

The CBCT images were taken at 12 mA and 70–90 kV with a Scanora Soredex scanner with the patient seated in the natural head position. Each whole image was first cropped to isolate a smaller field of view surrounding the vertebra of interest, either C2 or C3. Gray levels, which are equivalents of the BMD, were obtained for C2 and C3 at T1 and T2 at the same anatomical positions in the vertebral body (Fig. 1). This process was repeated for both C2 and C3 for all 20 images.

The CVM stage was categorized according to the Hassel and Farman method.[6] This method categorizes CVM into six stages depending upon the change in shape and concavities of the cervical vertebrae C2, C3, and C4. The mandibular length was measured as the distance from condylion (most posterior-superior point on the condyle), to anatomic gnathion (midpoint between the most anterior-inferior points on the bony chin) (Fig. 2). The vertebral variable (mean, SD), CVM stages, and mandibular length between T1 and T2 were compared.

Statistical Analysis

The study data were analyzed using the SPSS software (Statistical Package for Social Sciences for Windows, version 22.0. Released 2013. Armonk, NY: IBM Corp). Wilcoxon signed-rank test was used to compare the mean BMD values in C2 and C3 areas between pre- and post-functional therapy treatment time intervals. Student's paired t test was used to compare the mean mandibular length (in mm) between pre- and post-functional therapy treatment time intervals on the right and left sides. Mann–Whitney U test was used to compare the mean BMD values in C2 and C3 areas and mandibular length based on CVM stages during the pre- and post-treatment time intervals. Spearman's correlation test was used to estimate the relationship between the BMD values on C2 and C3 areas with right and left mandibular length during the pre- and posttreatment intervals. The level of significance (p value) was set at $p < 0.05$ for all tests.

RESULTS

The mean of the mean gray levels of both C2 and C3 showed significant increase in post-functional treatment (T2) (see Table 1). The mean of the mean gray levels for C2 vertebral body was significantly lower than that for C3 vertebral body both before (T1) and after (T2) treatment. The mean BMD values of C3 showed more increase post-functional therapy than the mean BMD values of C2 post-functional therapy.

The SD of gray levels was significantly greater before treatment than after treatment for C2 and C3 (Table 1). The SD values were more for C3 in pretreatment, but SD values decreased to the same levels in both C2 and C3 during the posttreatment.

The mandibular length on the both sides showed an increase during the observation time interval. The mandibular length on the right side showed a mean difference of −0.93 between pre- and post-functional therapy time intervals and the left side showed a mean difference of −1.73 (Table 2).

A positive correlation between BMD values and mandibular lengths is shown in the pre- and posttreatment intervals (Table 3).

The level of significance (p value) was set at $p < 0.05$ for all tests.

Table 1: Comparison of mean BMD values in C2 and C3 areas between the pre- and post-functional therapy treatment time intervals

Areas	Time	N	Mean	SD	Mean diff.	Z	p value
C2	Pre-Rx	9	338.94	60.12	−52.67	−2.666	0.008
	Post-Rx	9	391.61	52.97			
C3	Pre-Rx	9	344.11	85.20	−55.72	−2.666	0.008
	Post-Rx	9	399.83	53.88			

Table 2: Comparison of mean mandibular length (in mm) between the pre- and post-functional therapy treatment time intervals on the right and left sides

Side	Time	N	Mean	SD	Mean diff.	T	p value
Right	Pre-Rx	9	93.29	5.48	−0.93	−5.621	<0.001
	Post-Rx	9	94.22	5.32			
Left	Pre-Rx	9	93.71	5.76	−1.73	−5.718	<0.001
	Post-Rx	9	95.44	6.18			

Table 3: Spearman's correlation between the BMD values on C2 and C3 areas with right and left side lengths during the pre- and post-Rx intervals

Time	Areas	Values	Right side	Left side
Pre-Rx	C2	Rho	0.37	0.37
		p value	0.33	0.33
		N	9	9
	C3	Rho	0.28	0.28
		p value	0.46	0.46
		N	9	9
Post-Rx	C2	Rho	0.30	0.30
		p value	0.43	0.43
		N	9	9
	C3	Rho	0.22	0.22
		p value	0.58	0.58
		N	9	9

The correlation coefficients are denoted by "rho"

DISCUSSION

Lamparski in 1975 introduced the methods of maturational status assessment using cervical vertebrae. It was implemented by O'Reilly and Yanneilo and Bacetti et al.[7,8] However, Gabriel et al. emphasized on using more sensitive parameters instead of using morphological parameters in assessing CVM, thus to avoid intra and interobserver bias.[9,10]

Nestman et al. in the year 2011 reported that a classification of vertebral bodies based on the shapes (changes in concavity) had poor reproducibility. This made the CVM method to fail as an accurate growth assessment tool.[11] Previous methods using standard lateral cephalograms observe the shape changes of cervical vertebrae in various growing periods, whereas the measurement of BMD using CBCT provides a third dimension putting forth a quantitative analysis.[12]

Quantitative bone age assessment methods were evaluated by Chatzigianni and Halazonetis. Three-dimensional imaging opened new vistas in diagnosis and treatment planning. This led to the investigation by Shim et al. in 2012 to assess skeletal maturation using CBCT. They measured surfaces, areas, and volumes to assess skeletal age.[13]

Naitoh et al. in 2009 suggested that voxel values of mandibular trabecular bone derived from CBCT could be used to estimate the bone density.

In 2004, Crawford et al. digitally isolated cervical vertebrae from CBCT images and studied their volume and gray-level histograms and concluded that BMD and volume of cervical vertebrae were changed during the maturation.[1]

This study was aimed to determine whether additional information in the form of BMD distribution would be available using CBCT and whether it is useful in assessing skeletal maturity and growth potential. It was found that the BMD does change predictably during the adolescent growth period. The means of gray-level profiles of C2 and C3 vertebrae, which correspond to average BMD (BMD), were assessed from the CBCT images. The posttreatment timepoint showed greater mean gray level than at the pretreatment timepoint. As higher gray values indicate a higher level of mineralization, this indicates that there is a greater difference in mineralization between the two vertebrae after treatment than before treatment. This implies that active mineralization took place during the observation period, that is, adolescent growth period. The above results indicate that the CBCT-based analysis of gray levels of cervical vertebrae could provide information of BMD distribution that is changing along with skeletal maturation and mandibular growth.

The SD of gray levels indicates the variability of BMD resulting from bone modeling and remodeling. As the newly forming bone tissue has less tissue mineral density than preexisting bone tissue, the variability of tissue mineral density increases. In the current study, the SD of gray levels significantly decreased in both C2 and C3 posttreatments indicating that active bone remodeling has taken place during the observation period with more amount of less mineralized newly formed bone present at the posttreatment period.

The new bone formation occurs in two ways. Uncoupled bone modeling where resorption of preexisting bone tissue and formation of new bone tissue occur independently or by coupled bone remodeling process which comprises new bone formation after resorption. The newly formed bone tissue has less tissue mineral density than preexisting bone tissue. This causes variability of tissue mineral density.[14]

The constancy of CBCT-based BMD measurements is questionable due to the variations in the thickness of soft tissues

and the head position during the scan.[15] To alleviate these factors, we compared the gray-level parameters of consecutive vertebrae (C2 and C3) in the same CBCT image.

The use of CBCT in skeletal age assessment should be weighed on cost–benefit analysis practice of "as low as reasonably achievable" principle is mandatory. Effective dose from a typical orthodontic CBCT large field of view scan using a Scanora scanner is 68 mSv, while the dose from a digital lateral cephalometric radiograph is 5.6 mSv. However, in conditions like impacted or ectopic tooth, pathologies, temporomandibular dysfunctions, airway compromises, and cleft palate where routine lateral cephalogram is not sufficient enough to provide pertinent diagnostic data and CBCT imaging becomes obligatory, the clinicians can assess skeletal age from readily available CBCT, thus avoiding additional radiographic exposure.[16]

The CBCT has significant advantages like low effective radiation dose, low operational cost and high resolution level which can be used for obtaining three-dimensional images of craniofacial structures, the CBCT machine is compact and is best suited for dental clinics and it has been proposed as a diagnostic method for the determination of BMD.

Conclusion

Cervical vertebrae exhibit increase in BMD values during the peak mandibular growth period which is the optimal time for functional appliance therapy, and the BMD values showed a positive correlation with mandibular length increments and CVM stages.

Clinical Significance

This study proves that CBCT imaging may provide additional information about the growth status of a patient above and beyond that obtained from two-dimensional cephalometric radiographs. CBCT is an effective tool to analyze the volumetric parameter of BMD in routine dentofacial orthopedics with better accuracy and minimum distortion.

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