ORIGINAL ARTICLE

Two-dimensional to three-dimensional: A new three-dimensional cone-beam computed tomography cephalometric analysis

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ABSTRACT

Objectives of the Study: were (1) to develop a three-dimensional cephalometric analysis scheme applicable to assessing dentofacial deformities; and (2) to create a normative database of three-dimensional cephalometric measurements for adult North Karnataka population. **Materials and Methods:** A cross-sectional study was conducted on 40 male and 40 female adults with normal balanced facial profile and occlusion. Cone-beam computed tomography (CBCT) images obtained in digital imaging and communications in medicine format and the anatomic Cartesian three-dimensional cephalometric reference system according to Swennen *et al*. was used to standardize the reference planes. Cephalometric analysis was performed using various landmarks. New three-dimensional cephalometric analyses appropriate for orthognathic surgery as well as new parameters were used in this study. **Results:** The cephalometric norms generated in this study were comparable with those reported in the literature for conventional two-dimensional cephalometric analysis and unique features of North Karnataka population. The results showed significant differences between males and females in most of the facial measurements ($P < 0.0001$). **Conclusion:** This is the first database of three-dimensional cephalometric norms based on CBCT of the North Karnataka population. Norms generated were comparable with those reported in the literature with the conventional two-dimensional cephalometry: More accurate and reliable. Moreover, three-dimensional cephalometric analysis has the potential of incorporating new measurement methods that are difficult if not impossible in two-dimensional cepholmetric analysis. This method of cephalometric analyses can be useful in diagnosis and treatment planning for patients with dentofacial deformities.

Key words: Cone-beam computed tomography orthognathic surgery cephalometrics AMEAnalysis

Introduction

Cephalometric analysis has been a key element in diagnosis and treatment planning for orthodontic and orthognathic surgery patients. However, errors in identification of landmarks, their projection in two dimensions, superimposition of anatomical structures, and implications relative to head orientation have raised questions about the reliability of the analyses.[1,2] Therefore, several methods have been attempted to achieve a three-dimensional evaluation from the two-dimensional cephalographs.[3-5]

In recent times, several advantages of cone-beam computed tomography (CBCT) have been reported, including the ability to assess an image from the three planes, the ability to obtain life-sized three-dimensional images, and the lack of distortion or overlapping structures.[6] Moreover, it is not essential to make a fine adjustment of head position during imaging and analysis, because the points maintain their spatial relationships.[7] Some authors have reported ease of landmark identification and high precision of superimposing images with CBCT.[8,9]

van Vlijmen *et al*.[10,11] have reported clinically relevant differences between angular measurements taken from

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two-dimensional postero-anterior cephalographs and those from radiographs or three-dimensional models constructed from CBCT scans. Gribel *et al*.[12] concluded that measurements taken from a conventional lateral cephalogram were significantly different than those taken from a CBCT scan of the same person. Therefore, they presented a mathematical formula to enable the correction of two-dimensional into three-dimensional CBCT measurements.

Several investigators have attempted to develop three-dimensional analyses to cope with the huge amount of information provided by the three-dimensional technologies. Farronato *et al*.[13] proposed a 10-point three-dimensional analysis of CBCT images directly digitized on the rendered view. They evaluated the reliability and reproducibility of their method and compared their results to two-dimensional data. However, norms of the variables were not reported in their study, probably because of the small sample size and a wide range in age. Cheung *et al*.[14] have reported three-dimensional cephalometric norms on the basis of CBCT scans from a Chinese population. Bayome *et al*.[15] have reported an assessment of the relationships among the cephalometric variables and evaluated the curved nature of the mandible and maxilla. As there are no literature reports of the latter two with respect to North Karnataka population, the aim of this study were to assess three-dimensional cephalometric variables (with the inclusions of new parameters) from a normal occlusion sample and to evaluate the relationships among skeletal and dentoalveolar variables through a three-dimensional dephalometric analysis.

Objectives of the Study

1. To develop a three-dimensional cephalometric analysis scheme applicable to assessing dentofacial deformities;
2. To create a normative database of three-dimensional cephalometric measurements for adult North Karnataka population; and
3. To evaluate the relationships among skeletal and dentoalveolar variables through a three-dimensional cephalometric analysis.

Materials and Methods

A total of 80 North Karnataka young adults (40 men and 40 women; 24.29 ± 2.4 years) with normal occlusion were recruited from the A.M.E's Dental College and Hospital (Raichur, India), and the patients reporting for the general dental checkup in the private practices (Raichur, India). Informed consent was obtained from all the individuals going through the CBCT study.

The inclusion criteria were as follows:

1. Balanced facial appearance decided by agreement of two independent orthodontists;
2. Class I skeletal relationship;
3. Class I molar and canine relationship;
4. Full permanent dentition with the exception of the third molars;
5. 1- to 3-mm arch length discrepancy in each jaw;
6. Normal curve of Spee of 0-2 mm;
7. Absence of dental rotation;
8. Coincidental facial and dental midlines;
9. Absence of extensive restorations involving the proximal areas or the labial surfaces;
10. No previous orthodontic treatment; and
11. No acute or previous temporomandibular disorder.

The CBCT scans were acquired with an iCAT (Imaging Sciences International LLC, 1910, North Penn Road, Hatfield PA-19440) CBCT scanner and data were provided by Insight CBCT machine (Insight CBCT Machine- Insight CBCT, Shivajinagar, Pune-411005 MH, India). Subjects were positioned such that the softtissue contours of their faces were included in the scan. The following settings were applied: Voxel size: 0.25 mm beam diameter: 16 cm × 13 cm, scan time: 26.9 s. The voxels were exported in the digital imaging and communications in medicine format. Invivo 5.1 (Anatomage, San Jose, CA, USA) software was used to reconstruct the voxels, view, digitize, and measure the CBCT scans. First, reorientation of the head position of each scan was performed. Nasion (N) was selected as the origin of the X, Y, and Z coordinates. The horizontal plane (X) was the plane passing through N and parallel to the plane defined through the right and left orbitales (Or) and the left porion (Po), while the midsagittal plane (Y) was defined as the perpendicular plane passing through the origin N and anterior nasal spines. The vertical plane (Z) was perpendicular to both X and Y passing through N [Figure 1].

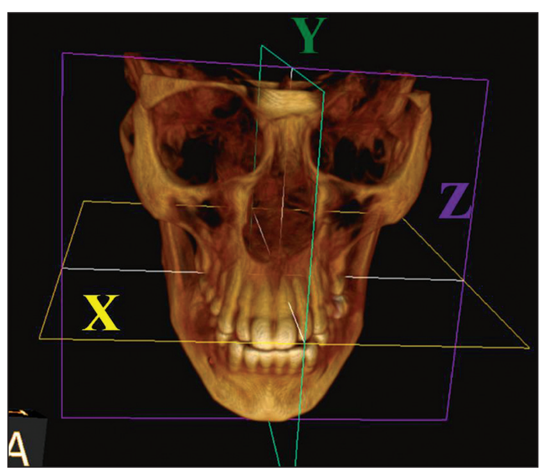

Figure 1: Three-dimensional Cartesian grid

Table 1 shows the definition of the hard- and softtissue landmarks digitized on the three-dimensional-rendered view of the images. The software calculated the linear and angular dimensions between certain landmarks, according to the definitions given in Figures 2-7 and Tables 2-6.

Table 1: Definitions of the three-dimensional skeletal and dentoalveolar landmarks

Landmark	Definition
Cranium	
Nasion (N)	The junction between the nasal and frontonasal sutures
Sella (S)	The center of the sella turcica on the midsagittal plane
Porion (Po)	The MSP on the upper rim of the external auditory meatus
Orbitale (Or)	The most inferior point on the lower rim of the orbit
Zygomatic point (Z)	The point on orbital rim showing the frontozygomatic suture
Maxilla	
Anterior nasal spine (ANS)	The most anterior point on the floor of nose
Posterior nasal spine (PNS)	The most posterior point on the floor of nose
Maxillary point (M)	The center of the concavity of the zygomatic process of the maxilla
A point (A)	The deepest point between ANS and prosthion at the midsagittal plane
Maxillary tuberosity (Max. T)	The most inferior and lateral point on the maxillary tuberosity
Canine eminence (CE)	The point on the surface of the maxilla corresponding to the canine root apex
Maxillary first molar (U6)	Mesiobuccal cusp of the upper first molar
Mandible	
B point (B)	The deepest point between pogonion and the alveolus of the lower incisors on the midsagittal plane
Pogonion (Pg)	The most forward-projecting point on the anterior margin of symphysis menti on the midsagittal plane
Gnathion (Gn)	The most inferior point anterior on the anterior margin of symphysis menti on the midsagittal plane
Menton (Me)	The lowermost point on the symphysis menti on the midsagittal plane
Mandibular body curve (MBC)	The most convex point on the curvature, midway between the inner and outer borders of the mandibular body
Gonion (Go)	The midway between the lowermost point on the posterior border of the ramus and the most posterior point on the lower border of the mandible
Sigmoid notch (Sig)	The deepest point on the sigmoid notch
Condylion (Co)	The uppermost point at the center of the condyle
Lateral condyle (Lat Co)	The most lateral point on the mandibular condyle
Medial condyle (Med Co)	The most medial point on the mandibular condyle
R point	The midpoint of SN

ANS: Anterior nasal spine, PNS: Posterior nasal spine, MBC: Mandibular body curve, MSP: Most superior point

To calculate the mandibular body curve (MBC) length, the coordinates of the menton (Me) and the right and left gonion (Go) and MBC points, which lie on the most convex

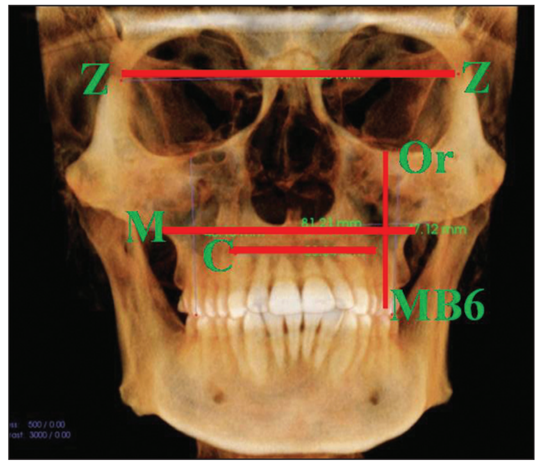

Figure 2: Frontal view

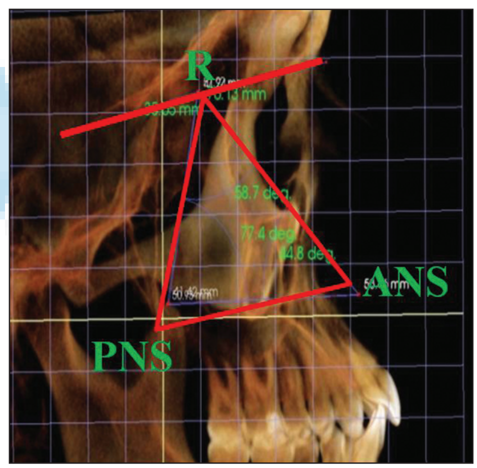

Figure 3: Lateral view maxilla

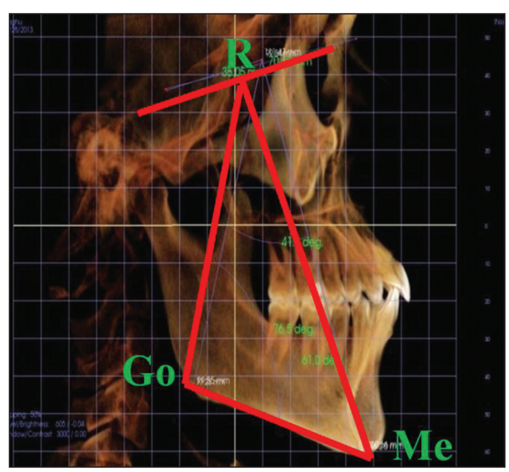

Figure 4: Lateral view mandible

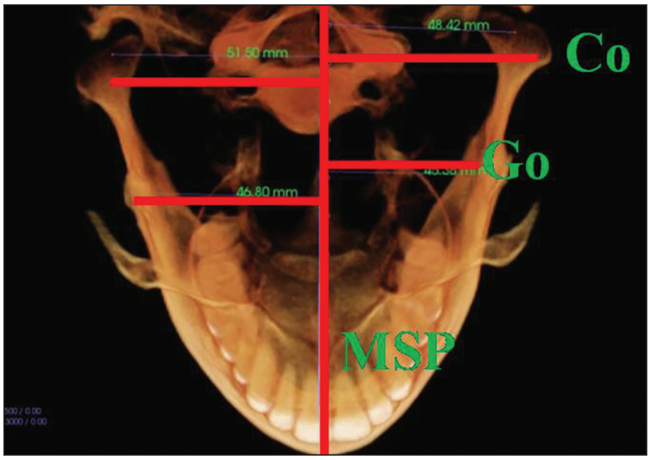

Figure 5: Most superior point to condylion and gonion

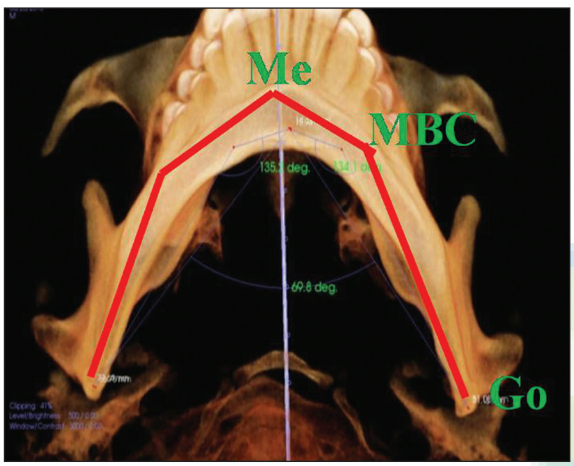

Figure 6: Mandibular body

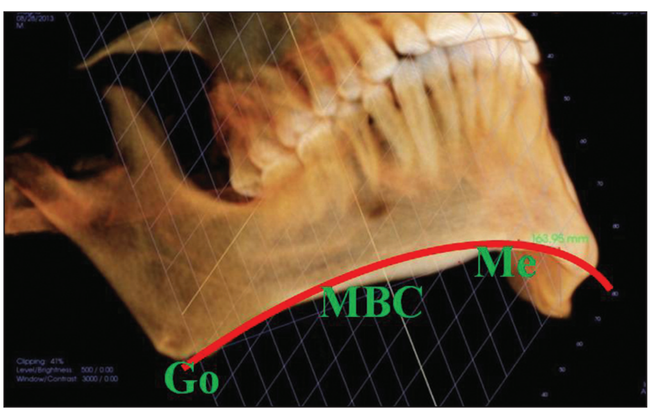

Figure 7: Mandibular basal curve length

point on the curvature of the mandibular body midway between the inner and outer borders [Figure 7], were used. The 4th-degree polynomial equation f(x) of the best fitting curve that passed through the 5-points was generated as an approximation of the curvature of the mandibular body.

$$f(x) = p1x^4 + p2x^3 + p3x^2 + p4x + ps \quad (1)$$

Table 2: Frontal view (four linear measurements)

Measurement landmarks	Parameter measured
Z-Z	Upper facial width
Or-MB6 (right and left)	Maxillary height
M-M	Posterior maxillary basal width
CE-CE	Anterior maxillary basal width

Table 3: Lateral view of maxilla (three angular and three linear) measure S-N and measure from a midpoint of SN

Measurement landmarks	Parameter measured
ANS-R-PNS	Maxillary angle to cranium
R-PNS-ANS	Maxillary posterior angle
PNS-ANS-R	Maxillary anterior angle
R-PNS	Maxilla to cranium lentgh posterior
PNS-ANS	Maxillary lentgh
ANS-R	Maxilla to cranium lentgh antterior

ANS: Anterior nasal spine, PNS: Posterior nasal spine

Table 4: Lateral view mandible (three angular and three linear) measure S-N and measure from a midpoint of SN

Measurement landmarks	Parameter measured
Me-R-Go	Mandibular angle to cranium
R-Go-Me	Mandibular posterior angle
Go-Me-R	Mandibular anterior angle
R-Go	Mandible to cranium lentgh posterior
Go-Me	Mandibular plane length
Me-R	Mandible to cranium lentgh posterior

Table 5: Posterior view of mandible (measurements to MSP)

Measurement landmarks	Parameter measured
Co-MSP (right)	Condylion to midsagittal plane
Co-MSP (left)	
Go-MSP (right)	Gonion to midsagittal plane
Go-MSP (left)	

MSP: Most superior point

Table 6: Mandibular body measurements

Measurement landmarks	Parameter measured
Go right-Me-Go left	Menton angle
Go-MBC-Me (right)	MBC angle (right)
Go-MBC-Me (left)	MBC angle (left)
Me-MBC (left)	Anterior mandibular length
MBC-Go (left)	Posterior mandibular length
Me-MBC (right)	Anterior mandibular length
MBC-Go (right)	Posterior mandibular length

MBC: Mandibular body curve

It was found that the polynomial of the 4th order approximated the curvature of the mandibular body with tolerable, or even negligible, mean square error.

The same procedures were followed to calculate the length of the curve of the basal arch of the maxilla by incorporating the A point, right and left canine eminence, and maxillary tuberosity, where a and b in the equation are the values of X coordinates of A point and maxillary tuberosity, respectively [Figure 8].

Cephalomteric Analysis

Landmark identification performed by the same operator (D.G) twice at an interval of 7 days for ruling out the bias/Landmark Error.

Landmarks and reference planes were oriented at a standardized position: The anatomic Cartesian three-dimensional cephalometric reference system according to Swennen and Schutyser[16] [Figure 1].

(1) Frontal view [Figure 2], (2) lateral view of maxilla [Figure 3], (3) lateral view of mandible [Figure 4], (4) posterior view of mandible [Figure 5], (5) mandibular body [Figure 6], (6) mandibular basal curve length [Figure 7], and maxillary basal curve length [Figure 8] were analyzed with the reference points as shown in respective figures and the values were calculated for both males and females samples to draw the statistical results.

Statistical Analysis

Statistical evaluation was performed using SPSS software version 16.0 (SPSS Inc., Chicago, IL, USA). Frequencies, means and standard deviations of all the linear and angular measurements were generated. Independent *t*-tests and one-way analysis of variance were used to analyze the gender- and age -related differences, respectively. Gender dimorphism was evaluated by an independent samples *t*-test. Correlations among skeletal and dentoalveolar measurements were calculated by means of Pearson's correlation coefficient. Correlations among liner and angular measurements by Karl Pearson's correlation coefficient method were performed.

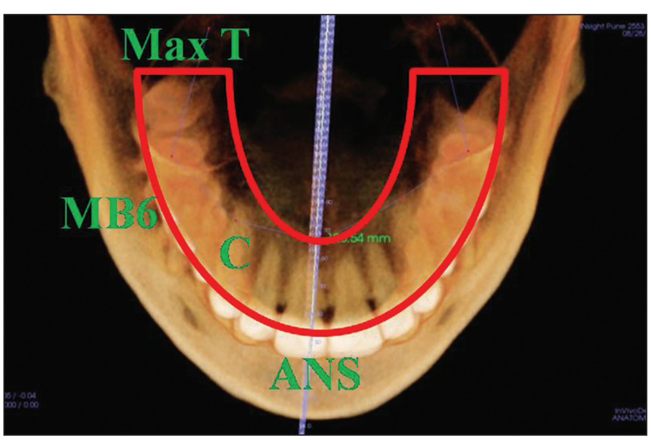

Figure 8: Maxillary basal curve length

To assess the reliability of the digitizing process, 10 CBCT scans were redigitized by the same operator, 2 weeks later. The intraclass correlation coefficient (ICC) between the duplicate measurements showed high reliability [ICC ranged between 0.997 and 0.931].

Results

There were significant differences in skeletal and dentoalveolar variables between both the sexes. The results of maxillary frontal view showed a statistical significant variation in the maxillary height (right and left sides) in both genders. Statistically results showed males having more maxillary height than females. The maxillary anterior basal width also showed statistically significant increase in males as compared to females [Table 7, I. 2 and 4].

On the lateral view of maxilla, the maxillary anterior angle showed a significant increase in males than females. In the same view, maxilla to cranium length anterior was more for females than males [Table 7, II. 5, 8 and 10]. The results of lateral view of mandible showed statistically significant differences in the mandibular anterior angle with the females showing lesser prominence values then males. The mandibular cranium lengths both anterior and posterior were found to be more in males than females [Table 7, III. 13 and 14]. Statistical differences were evident in both condylar to midsagittal plane (right and left) and the Go -to-midsagittal plane (right and left) dimensions in both the genders [Table 7, IV]. The mandibular body showed statistically significant differences in Me angle and anterior mandibular body length (left) in both the sexes [Table 7, V. 21 and 24]. The basal curve of the mandible showed a longer curve length in male subjects (176.50 mm) than in female subjects (170.30 mm) ($P < 0.002$), but there was no significant difference in the maxillary basal curve length ($P < 0.0017$) [Table 7, VI].

Correlations among liner and angular measurements by Karl Pearson's correlation coefficient method was performed and most of the values showed a significant correlation with r values >0.31 at 5% level of significance ($P < 0.05$).

Discussion

The three-dimensional evaluation of cephalometric variables assists clinicians in obtaining enhanced diagnosis and in treatment planning. Traditionally, two-dimensional cephalometric analyses suffer from inherent drawbacks related to the two-dimensional technique, which may have led to errors in their norms. Therefore, three-dimensional analysis may represent the key to overcoming these weaknesses.

Table 7: Results

Parameters	Males mean (SD)	Females mean (SD)	*P* value
I. Frontal view (four linear measurements)			
Upper facial width	94.27 (2.22)	95.07 (1.67)	0.2041
Maxillary height (right/left)	45.16 (1.84)/45.45 (1.37)	40.64 (1.63)/39.84 (1.93)	0.0001*/0.0001*
Posterior maxillary basal width	38.51 (1.52)	38.73 (1.55)	0.6650
Anterior maxillary basal width	34.90 (1.35)	32.26 (2.18)	0.00001*
II. Lateral view maxilla (three angular and three linear) measure S-N and measure from a midpoint			
Maxillary angle to cranium	58.56 (2.40)	54.17 (2.90)	0.0001*
Maxillary posterior angle	69.31 (2.59)	71.38 (4.13)	0.0645
Maxillary anterior angle	47.25 (2.68)	48.40 (3.34)	0.4193
Maxilla to cranium length posterior	49.12 (2.78)	47.21 (3.20)	0.0500*
Maxillary length	47.42 (1.76)	47.50 (2.23)	0.9023
Maxilla to cranium length anterior	51.79 (1.73)	53.79 (2.06)	0.0020*
III. Lateral view mandible (three angular and three linear) measure S-N and measure from a midpoint			
Mandibular angle to cranium	45.80 (2.42)	46.41 (2.41)	0.4267
Mandibular posterior angle	74.20 (2.33)	73.13 (2.73)	0.1903
Mandibular anterior angle	61.61 (1.34)	52.90 (1.36)	0.00001*
Mandible to cranium length posterior	95.30 (2.36)	84.35 (3.17)	0.00001*
Mandibular plane length	83.07 (2.43)	82.45 (1.93)	0.3775
Mandibular to cranium length anterior	106.75(4.14)	101.93 (3.37)	0.0003*
IV. Posterior view of mandible (four linear)			
Co-MSP (right)	53.41 (1.80)	47.46 (2.32)	0.0001*
Co-MSP (left)	46.22 (1.74)	39.27 (2.00)	0.0001*
Go-MSP (right)	49.12 (2.78)	42.63 (3.27)	0.0001*
Go-MSP (left)	49.27 (1.78)	36.67 (2.19)	0.0001*
V. Mandibular body (three angular and four linear)			
Menton angle	67.38±1.85	60.11±3.18	0.0001*
MBC angle (right)	135.05±2.56	134.20±2.97	0.3385
MBC angle (left)	129.30±2.08	129.30±4.86	1.0000
Anterior mandibular body length (left)	12.56±1.14	14.95±1.39	0.0001*
Posterior mandibular body length (left)	72.87±1.96	72.66±1.78	0.7186
Anterior mandibular body length (right)	16.65±2.30	16.00±1.92	0.3381
Posterior mandibular body length (right)	69.98±2.84	68.47±1.44	0.0563
VI. Basal curve lengths			
Mandibular basal curve length (Go-MBC-Me-MBC-Go)	176.50 (±2.95)	170.30 (±6.16)	0.0002*
Maxillary basal curve length (Max. T-CE-ANS-CE-Max. T)	127.45 (±2.54)	123.25 (±4.94)	0.0017*

SD: Standard deviation, MSP: Most superior point, MBC: Mandibular body curve, Max. T: Maxillary tuberosity, ANS: Anterior nasal spine, *$P < 0.005$

Cheung *et al*.[16] evaluated the mandibular body length from Me to Antegonion and from Me to Go. However, they overlooked the assessment of the curved nature of the mandible and maxilla. Lee *et al*.[17] proposed the MBC point and reported a significant difference between the asymmetric and normal occlusion groups in the posterior mandibular body length, but this difference was not significant in the mandibular body length (Me-Go).

In our study, a new approach was applied to evaluate the curve length of the mandibular body by calculating the length of the curve passing through Me, MBC, and Go to achieve a more accurate representation of the length of the mandibular body instead of using an approximation of the curve with a line. The maxillary and mandibular curve lengths might guide clinicians in treatment planning by shedding light on the limits of the basal arches that enclose the teeth.

A previous study using three-dimensional analysis reported normal values of selected cephalometric variables, but no attempt was made to evaluate the relationships among these variables.[14] In our study, significant strong-to-moderate correlations of facial heights were noticed with several transverse variables, such as upper facial width and Go-to-midsagittal measurement as shown in Table 7. Moreover, the upper facial width had strong-to-moderate correlations with the maxillary height and length and MBC length. These findings may suggest the existence of relationships among facial dimensions in the normal occlusion sample.

Regarding the condyle, You *et al*.[18] suggested that the condylar unit, consisting of condyle, condylar neck, and part of the ramus, plays a central role in mandibular asymmetry, whereas Huntjens *et al*.[19] found condylar asymmetries did not correlate well with facial asymmetry. In our study, the reported correlation between the condylar and mandibular variables might be attributed to the adaptive capacity of the condyle, as suggested by Enlow and Hans.[20] For example, in Table 7, IV 17 and 18, the negative correlation between the condylar anteroposterior inclination and the gonial angle tends to preserve the proportion between the height of the mandible and its sagittal position in the normal occlusion population.

Recently, the difference in ramal length from one side to the other was reported as a characteristic of both mandibular-retrusion and prognathism groups.[21]

In our results, there was no significant difference between the right and left sides. However, Shah and Joshi[22] reported asymmetry in the normal occlusion population with pleasing facial features. This discrepancy might be the result of difficulties in landmark identification in their study, due to superimposition of anatomical structures.

In our study, the comparison between male and female subjects showed significant differences in several vertical and transverse measurements, but there were no significant differences in the sagittal dimensions. These results were in agreement with Thilander *et al*.[23] who reported that the linear craniofacial measurements were larger in male subjects than in female subjects, while angular measurements showed no statistical differences. The anterior mandibular length was found to be more in males than in females confirming the more prominent chin in males. On the contrary, the results of our study confirmed that the females of North Karnataka region have increased length of maxillary anterior to the cranial base, which was evident clinically as a gummy smile. These findings are of clinical importance when any orthognathic surgery is performed to match with the normal facial preferences for a particular ethnic group. This might suggest that the dimensions of the face played a major role in the gender dimorphism.

We limited our subject base to young adults to eliminate the effect of growth, because changes in facial features by age have been reported.[23,24] In addition, our method used for digitization of the CBCT images might be technique sensitive. Further studies are recommended to evaluate the operator learning curve; the reliability of the measurements, the predictors of the correlated variables, and norms for different ethnic groups. The three-dimensional evaluation of cephalometric variables assists clinicians in obtaining enhanced diagnosis and treatment planning. Three-dimensional analysis overcomes drawbacks/weaknesses of the two-dimensional analysis. This is the first three-dimensional cephalometric analysis for the North Karnataka population. This analysis/database will be a useful reference for evaluation of the Indian facial form. This database will also be of value for orthodontist and oral and maxillofacial surgeons in India. These normal values could be used as a reference for assessing dysmorphology and evaluating treatment outcomes in young adults. 20-30 years age range: Sample recruited comparable to age of patients likely to have orthognathic surgery. By limiting age range-possibility of aging differences were ruled out. SN plane; most superior point plane; FH plane and zero meridian plane were used for facial orientation. Linear/mill metric measurements should not be used exclusively for the clinical diagnosis and treatment planning and for comparing results and treatment outcome. Angular/ratios/differences between two linear measurements are more acceptable of reflecting the harmony or any discrepancy of facial features. It can be very useful and accurate for comparing results and treatment outcome. Hence, the angular measurements, ratios and differences in linear measurements (e.g., asymmetric ramus length) in our analysis are of great help for the planning of orthognathic surgery and treatment outcome.

Limitation of the Study

Artifacts in the CBCT by dental amalgam fillings or bridges may interfere with the analysis of molar regions.

Softtissue analysis is not included and requires virtual three-dimensional model set up.

Conclusion

A new three-dimensional CBCT cephalometric analysis scheme applicable to assessing dentofacial deformities is developed. This is the first database of three-dimensional cephalometric norms generated based on CBCT of the North Karnataka population.

Norms generated were comparable with those reported in the literature with the conventional two-dimensional cephalometry: More accurate and reliable. Moreover, three-dimensional cephalometric analysis has the potential of incorporating new measurement methods that are difficult if not impossible in two-dimensional cepholmetric analysis.

Strong-to-moderate correlation values were found among several vertical and transverse variables through three-dimensional cephalometric analysis. This method of cephalometric analyses can be useful in diagnosis and treatment planning for patients with dentofacial deformities.

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