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Precision of manual landmark identification between as-received and oriented volume-rendered cone-beam computed tomography images

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Introduction: The objective of this study was to evaluate the effect of the orientation of cone-beam computed tomography (CBCT) images on the precision and reliability of 3-dimensional cephalometric landmark identification. **Methods:** Ten CBCT scans were used for manual landmark identification. Volume-rendered images were oriented by aligning the Frankfort horizontal and transorbital planes horizontally, and the midsagittal plane vertically. A total of 20 CBCT images (10 as-received and 10 oriented) were anonymized, and 3 random sets were generated for manual landmark plotting by 3 expert orthodontists. Twenty-five landmarks were identified for plotting on each anonymized image independently. Hence, a total of 60 images were marked by the orthodontists. After landmark plotting, the randomized samples were decoded and regrouped into as-received and oriented data sets for analysis and comparison. Means and standard deviations of the x-, y-, and z-axis coordinates were calculated for each landmark to measure the central tendency. Intraclass correlation coefficients were calculated to analyze the interobserver reliability of landmark plotting in the 3 axes in both situations. Paired *t* tests were applied on the mean Euclidean distance computed separately for each landmark to evaluate the effect of 3-dimensional image orientation. **Results:** Interobserver reliability (intraclass correlation coefficient, >0.9) was excellent for all 25 landmarks for the x-, y-, and z-axes on both before and after orientation of the images. Paired *t* test results showed insignificant differences for the orientation of volume-rendered images for all landmarks except 3: R1 left ($P = 0.0138$), sella ($P = 0.0490$), and frontozygomatic left ($P = 0.0493$). Also midline structures such as Bolton and nasion were plotted more consistently or precisely than bilateral structures. **Conclusions:** Orientation of the CBCT image does not enhance the precision of landmark plotting if each landmark is defined properly on multiplanar reconstruction slices and rendered images, and the clinician has sufficient training. The consistency of landmark identification is influenced by their anatomic locations on the midline, bilateral, and curved structures. (Am J Orthod Dentofacial Orthop 2017;151:118-31)

Three-dimensional craniofacial imaging such as computed tomography (CT) and cone-beam CT (CBCT) offers great potential in diagnosis and treatment planning of complex skeletal deformities and assessment of growth and treatment effects.[1-8] Conventionally, craniofacial analyses based on 2-dimensional (2D) cephalometry have several limitations: magnification, distortion, overlapping of craniofacial

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structures, difficulty in locating hidden anatomic structures, and so on.[9-15] These limitations were also highlighted during comparisons of measurements between dry skulls and those on 2D cephalograms while searching for the anatomic truth.[16] With the advancements in 3-dimensional (3D) imaging modalities in the last decade, these limitations of 2D analysis have been addressed to a certain extent.[5,17]

Synchronal literature in this decade has emphasized the pivotal role of 3D CT and CBCT imaging modalities in the 3D cephalometric analysis.[2,5,10,17-20] But the challenge for clinicians at present is to understand and interpret 3D imaging.[11] Conventionally, cephalometric analysis is based on the landmark identification and plotting on 2D images. Training and familiarization with the location of landmarks on 3D images is essential because landmark identification errors are a major source of cephalometric errors.[15] Therefore, the need for new guidelines for 3D landmark identification is warranted.

Many studies in recent years have evaluated the reliability of landmark identification on CT and CBCT data.[21-26] Apart from the errors due to the lack of experience,[27-31] the perceptions of the observer in localizing the anatomic landmarks on 3D images and the head orientation also may influence landmark plotting on 3D images.[32] A few studies have evaluated the effect of head orientation in CBCT synthesized posteroanterior and lateral cephalograms[22,24] and 3D CBCT imaging modality[21,23,25] on cephalometric measurements. A significant difference was found between dry skull cephalometric measurements and CBCT synthesized lateral cephalogram measurements[22,24] in different head positions, whereas the differences in measurements on 3D CBCT images were found to be statistically insignificant from dry skull measurements.[21-23,25] Studies by Tomasi et al[23] and Berco et al[25] have shown statistically insignificant differences between nonoriented CBCT images and dry skulls; the data were derived using only a single skull for measurements. Similarly, Ludlow et al[21] and Hassan et al[22] have also shown insignificant measurement differences between nonoriented CBCT data and dry skulls with 4 and 10 linear measurements, respectively.

These studies have tried to provide insight into the effect of head orientation on the accuracy of linear measurements but not on the anatomic landmark positions in 3 dimensions with a change in orientation[21-26] (Table I). To authenticate the accuracy of plotted landmarks, baseline data (gold standard) were required to be derived from the markings on the actual skull models for comparison. Since it is not possible to obtain gold standard measurements directly from living subjects, data can possibly be derived by repeated landmark plotting on CBCT images. The precision of landmark plotting could be influenced by the orientation of the volume-rendered image. Direct evaluation of precision and consistency of 3D landmark plotting with and without orientation has not been investigated.[32] In the light of such data with uncertain standpoints on the effect of orientation on landmark identification, this study was conducted to evaluate the effect of orientation on the precision of 3D landmark identification vis-à-vis as-received CBCT images.

MATERIAL AND METHODS

Ten CBCT images were collected randomly from an orthodontic clinic database retrospectively irrespective of age, sex, and ethnicity. The ethics committee of All India Institute of Medical Sciences, New Delhi, India approved this study, and no patients were recruited for this study separately. The CBCT scans were obtained using an i-CAT next generation machine (Imaging Sciences International, Hatfield, Pa) with a field of view of 17 × 22 cm and a scan time of 26 seconds. The data were saved in DICOM (version 1.7) format with an isometric voxel size of 0.25 to 0.30 mm. CBCT scans had been taken with the subject sitting upright and in natural head position.

Three experienced orthodontists (R.B., S.K., S.C.) were asked to plot the landmarks on the CBCT images and were called O1, O2, and O3. Furthermore, 2 observers (A.G., V.S.) separately were asked to perform orientations of the CBCT images and randomization of the data for blind marking for the experiment. The observer who had performed the orientations was called O4, and the observer who had randomized the data for blind marking was called O5. Observer O5 generated 3 random sets of CBCT data referred to as SI, SII, and SIII for landmark plotting of the 3 observers O1, O2, and O3.

Twenty-five commonly used cephalometric landmarks were selected, and operational definitions of each landmark[33,34] in the 3 planes (axial/xy plane, coronal/xz plane, and sagittal/yz plane) were derived.[18,28,31] In addition to the cross-sectional slices, 3D volume-rendered images were also used to confirm landmark positions. Three axes were defined: x-axis in the right-left direction, y-axis in the anteroposterior direction, and z-axis in the inferior-superior direction. The 3 orthodontists who participated in the study were familiarized with each landmark and mutually agreed on the definitions of each landmark in 3 dimensions. They practiced on 5 anonymized CBCT images. Any ambiguity in locating landmarks was resolved through mutual discussion, and the landmark definitions were refined with the consensus of the expert orthodontists. It was decided to plot 11 landmarks in volume-rendered images directly and confirm them on