A technique for three-dimensional cephalometric analysis as an aid in evaluating changes in the craniofacial skeleton

Christy L. Haffner, DMD; Joel E. Pessa, MD; Vikram P. Zadoo, MD; Jaime R. Garza, MD, DDS

Abstract: A technique is presented for creating a standardized view for use in three-dimensional cephalometry. Three-dimensional cephalometric analysis has become a valuable tool in the assessment of skeletal remodeling, contour changes, and changes in proportion that occur with aging. Computer-assisted tomographic data can be used in either coronal or axial sections; the present study was performed with axially acquired data that was processed in several steps to achieve a standardized position of the facial skeleton for further evaluation. This technique may be a useful adjunct to standard cephalometrics to evaluate the craniofacial skeleton.

Key Words: Three-dimensional cephalometrics, Craniofacial skeleton, Cephalometric analysis

Two-dimensional cephalometric analysis was introduced in the early part of this century by Broadbent in the United States[1] and Hofrath in Germany;[2] it has since become one of the most important clinical and research tools in orthodontics for evaluating craniofacial growth and dentofacial deformities. Although cephalometric analysis was originally developed to study growth changes in the craniofacial complex,[3] other valuable uses have been discovered, including evaluating dentofacial proportions and determining the basis for a malocclusion, predicting growth values of a maturing individual, as a tool for making comparisons during active orthodontic treatment, and during surgical planning for individuals with complex dentofacial abnormalities. It is clear that cephalometric analysis has aided dentistry and medicine since its inception.

Despite the tremendous utility of two-dimensional cephalometrics, there may be factors that limit the scope of this analytical technique. For example, the two-dimensional cephalogram requires symmetry of anatomic landmarks, and it is less useful in evaluating patients with severe craniofacial anomalies.[5,6] In addition, although two-dimensional cephalometry can isolate points on the facial skeleton where sharp changes in contour or density occur, some areas of the facial skeleton are not as well visualized.

The recent advent of three-dimensional computer-assisted tomography (CT) has led to a refinement in preoperative planning for many surgical procedures.[7-10] Precise anatomic data unobtainable by other means can be acquired from a 3D radiological image.[7] The availability of personal computer software for the creation of 3D models[11] and the rapid acquisition of CT data with helical technology[12] has led to the widespread use of three-dimensional imaging in many institutions. Improved accuracy in diagnostic ability is possible with 3D scanning, especially in those individuals with marked facial asymmetry, such as hemifacial microsomia or oculo-auriculo-vertebral syndrome.[13]

The three-dimensional CT scan technique offers the opportunity to evaluate some points on the skeleton in greater detail and with more precision than the two-dimensional method allows. The standard cephalogram represents an average of the two sides of the face and allows evaluation of many well-defined areas. Because 3D imaging shows each side of the face separately, and because contours and surface detail are rendered in fine detail, additional knowledge of

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Figure 1
High-resolution 3D modeling enables additional points on the craniofacial skeleton to be identified and evaluated

Figure 2A
Using axially acquired CT data, a three-dimensional model is reconstructed

Figure 2B
Frontal alignment is performed first. A grid overlay can facilitate rotation of the reconstructed skeleton

Figure 2C
Orbitale (O) to orbitale is suitable for x-axis alignment. Image has been rotated 3 degrees clockwise to complete alignment

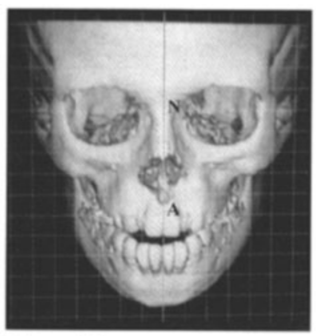

Figure 2D
Y-axis alignment is accomplished by centralizing a line drawn through nasion (N) and A-point (A)

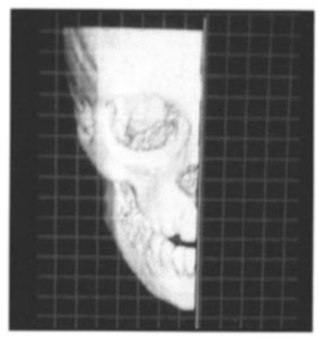

Figure 2E
Skeletal reconstruction can now be aligned on the z-axis. Initial step calls for the left side of the face to be removed

the skeleton can be gained (Figure 1). For example, changes in the position of the pyriform aperture, canine eminence, and anterior lacrimal crest that occur with aging can be evaluated with this technique.[14]

Another useful feature of three-dimensional cephalometry is the ability to correlate soft tissue and hard tissue points directly on the computer. This means skeletal points that are located at specific areas on the soft tissue contours of the face can be used. When using a soft tissue reconstruction, bone windows can be viewed simultaneously and the cursor on the soft tissue will automatically locate the corresponding skeletal point. This yields additional information in reference to the facial profile and contour.

One problem with using 3D CT scans is the lack of uniformity in viewing the reconstructed image. The purpose of this paper is to describe a technique that creates a standardized view for the study of three-dimensional cephalometry.

Materials and methods

CT scans were obtained from either data-archived tapes or optical discs stored at University Hospital. The standard protocol for the head CT scan procedure calls for data to be acquired with patients in the supine position and with a head inclination of 0 to 15 degrees. Slice interval can be set from 1 to 10 mm; for the purpose of this technique, only scans acquired at intervals of 3 mm or less were used because of the higher quality results obtained with this degree of definition. Both axial and coronal slices were obtained for most subjects. However, three-dimensional reconstruction with axial data may result in less information loss.[15]

Axial data were loaded onto an Ultrasparc Workstation (GE), and a 3D facial skeleton was created. All CT scans were reconstructed in three dimensions with existing software (GE/Sun), using Voxtool Program version 2.0 for the reformatting process (GE/Sun). High-resolution image construction as well as image manipulation is possible with most 3D software programs; image manipulation is necessary with this particular technique in order to align the skeletal model into a standardized view.

The technique for generating a standardized view in this model requires several steps. The sequence allows reproducible results to be obtained with a high degree of accuracy.

Description of technique

1. Using axial CT data acquired within the set limits, a three-dimensional reconstruction is created (Figure 2A).

2. Frontal alignment on the x- and y-axes is performed, facilitated by superimposing a grid overlay on the skeletal reconstruction (Figure 2B).

3. Orbitale-orbitale is suitable for x-axis alignment (Figure 2C). The

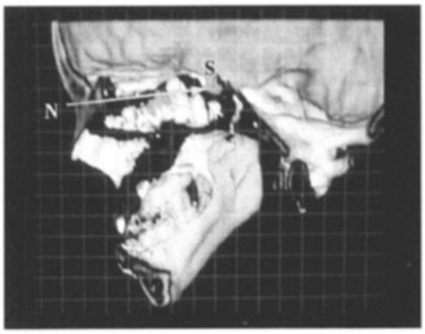

Figure 2F
Bisected face is turned to the right, and a line is drawn through nasion (N) and sella (S)

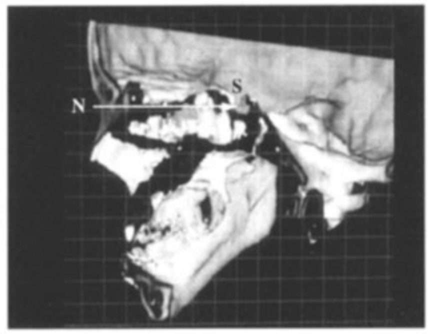

Figure 2G
The line drawn through sella and nasion is then rotated to a position perpendicular to the horizontal

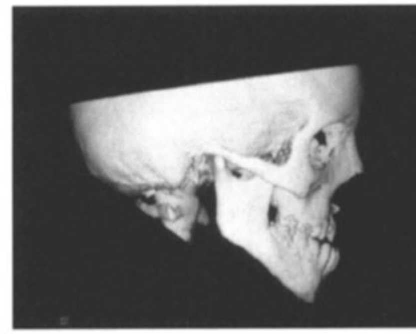

Figure 2H
As a final step, the skeleton is rotated 180 degrees, and is viewed in the standard right sagittal plane. Three-dimensional alignment has been accomplished

image is rotated clockwise in this case to obtain alignment.

4. Y-axis alignment is accomplished by centralizing a line through nasion and A-point (Figure 2D). A quick check for accuracy of rotational alignment can be made by measuring from nasion to the orbital walls on either side.

5. The skeletal reconstruction is aligned on the z-axis, using sella-nasion as the reference line. The face is bisected by dropping a vertical through the central face, nasion, and A-point (Figure 2E), then the left side of the face is removed.

6. The bisected facial skeleton is turned 90 degrees to the left (Figure 2F), nasion and sella are identified, and a line is drawn through these points.

7. The line through nasion and sella is rotated to a position perpendicular to horizontal (Figure 2G).

8. Finally, the face is rotated 180 degrees into the standard right sagittal plane (Figure 2H). With the facial skeleton in this position, any number of landmarks can be used. A line dropped from nasion perpendicular to sella-nasion has been found to be useful in measuring anteroposterior changes. In a similar fashion, the axis of sella-nasion can be used to measure vertical distances to a number of points on the facial skeleton.

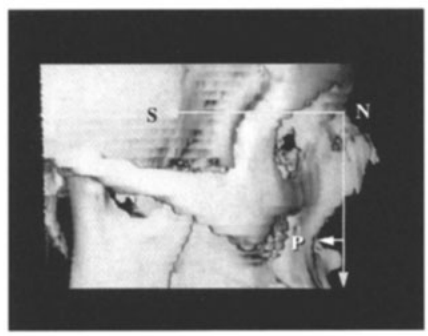

Figure 3A
An example of the utility of three-dimensional cephalometry. A perpendicular has been drawn to sella-nasion(SN). Note the position of the lateral pyriform aperture (P) relative to this vertical reference plane (short arrow) in a 29-year-old female

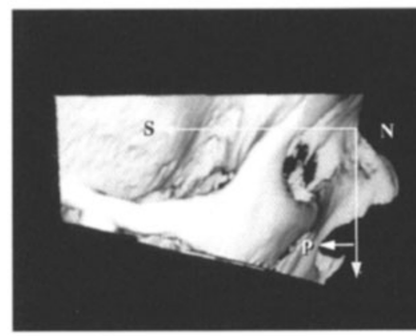

Figure 3B
The facial skeleton of a 99-year-old female placed in the standardized view. Note the increase in depth of the midface compared with the 29-year-old (Fig. 3A), as measured from perpendicular to sella-nasion to the lateral pyriform aperture. Other points, such as the canine eminence and anterior lacrimal crest, can be similarly evaluated

Discussion

In viewing the facial skeleton, standardized alignment is critical to obtaining reproducible data. The technique described creates alignment in three axes and enables the viewer to use three-dimensional cephalometry to gain additional information regarding craniofacial proportions and skeletal growth.

Behrents[3] used two-dimensional cephalometrics to study changes in the growth of the craniofacial skeleton in aging individuals in his longitudinal study and found that virtually every point on the cephalogram changes as a person ages. One of the principal tenets of the work is that craniofacial growth consists of continued expansion. This information has made a significant contribution to the understanding of craniofacial growth.

Three-dimensional cephalometrics can add to this body of information because it can discern additional points and landmarks on the face. An example of this is some recent work showing that the midface tends to retrude relative to nasion with advancing age (Figure 3A-B), even in individuals with a complete maxillary dentition.[14] This study was made possible only with the use of three-dimensional cephalometrics because the lateral pyriform and canine eminence could be accurately identified.

Three-dimensional cephalometric analysis is especially useful in patients with marked dentofacial asymmetries.[16] Three-dimensional image analysis has also become a standard technology in many institutions to improve preoperative diagnostic capabilities, including volumetric analysis.[17,18] Almost any data acquired by conventional means, including computer-assisted tomography, magnetic resonance imaging, and laser surface scanning, can be converted to 3D data with the appropriate software. As the level of the technology improves, the total dosage of radiation necessary also decreases. An excellent example of rapid data-acquisition is the advent of helical or spiral technology, which allows a complete head scan to be performed in approximately 5 minutes. Helical scans can be archived and later reformatted to any slice interval required to achieve extremely high-resolution three-dimensional modeling.

Although the cephalogram remains the standard for evaluating preoperative skeletal disharmony and for studying facial growth, 3D analysis of the facial skeleton offers some additional benefits. The technique presented represents a continuum in the growing ability to analyze the facial skeleton. The high resolution of the skeletal contour enables subtle changes in topography to be evaluated. Three-dimensional point evaluation may ultimately be supplanted by the ability to discern changes in contour and topography with techniques such as finite element or conformational analysis. As such, cephalometrics is an evolving field that interfaces with three-dimensional modeling technology.

Conclusions

Three-dimensional cephalometric analysis may be an effective tool for evaluating the craniofacial skeleton. A standardized view to assess changes is possible with a straightforward technique aligning three axes, which eliminates rotational variance. The three-dimensional facial skeleton can be viewed in the standard right sagittal plane and may provide additional information for the researcher as well as the clinician.

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