Comparison of Scientific Calipers and Computer-Enabled CT Review for the Measurement of Skull Base and Craniomaxillofacial Dimensions

**Martin J. Citardi, M.D.,¹ Brian Herrmann, M.D.,²
Chris S. Hollenbeak, Ph.D.,⁵ Brendan C. Stack, M.D.,⁵
Margaret Cooper, Ph.D.,³ and Richard D. Bucholz, M.D.⁴**

ABSTRACT

Traditionally, cadaveric studies and plain-film cephalometrics provided information about craniomaxillofacial proportions and measurements; however, advances in computer technology now permit software-based review of computed tomography (CT)-based models. Distances between standardized anatomic points were measured on five dried human skulls with standard scientific calipers (Geneva Gauge, Albany, NY) and through computer workstation (StealthStation 2.6.4, Medtronic Surgical Navigation Technology, Louisville, CO) review of corresponding CT scans. Differences in measurements between the caliper and CT model were not statistically significant for each parameter. Measurements obtained by computer workstation CT review of the cranial skull base are an accurate representation of actual bony anatomy. Such information has important implications for surgical planning and clinical research.

KEYWORDS: Computer-aided surgery, 3D CT model, cephalometrics

Since its introduction nearly 30 years ago, computed tomography (CT) imaging has been widely adopted in craniomaxillofacial and skull base surgery. Imaging quality has improved dra-

matically, and computer workstations now process CT images. Over the past decade, computer-aided surgery (CAS), which provides intraoperative stereotactic localization on preoperative imaging

Skull Base, volume 11, number 1, 2001. Reprint requests: Martin J. Citardi, M.D., Department of Otolaryngology and Communicative Disorders, Cleveland Clinic Foundation, 9500 Euclid Avenue, Desk A71, Cleveland, OH 44195. E-mail: mjcortl@pol.net. ¹Department of Otolaryngology and Communicative Disorders, Cleveland Clinic Foundation, Cleveland, OH; Departments of ²Otolaryngology–Head and Neck Surgery, ³Anatomy, and ⁴Neurosurgery, Saint Louis University, School of Medicine, St. Louis, MO; ⁵Department of Otolaryngology, Head and Neck Surgery, Pennsylvania State University, School of Medicine, Hersey, PA. Copyright © 2001 by Thieme Medical Publishers, Inc., 333 Seventh Avenue, New York, NY 10001, USA. Tel: +1(212) 584-4662. 1531-5010, p;2001,11,01,005,012,ftx,en;sbs00202x.

data, has also been introduced. These imaging computer workstations provide software tools for surgical planning and image review. Before these technologic developments, standardized plain-film radiograph analysis (i.e., cephalometrics) and cadaveric dissection provided anatomic information about craniomaxillofacial and skull base anatomic relationships.

Although the accuracy of computer-derived measurements based on CT data may seem reasonable, such an assumption overlooks potential sources of error. This study compares the performance of computer workstation review of CT data relative to scientific-grade calipers in assessing skull base and craniomaxillofacial dimensions.

MATERIALS AND METHODS

Five adult human cadaveric skulls were used for this study. A high-resolution thin-section (1-mm) axial CT (GE Advantage scanner, GE Medical Systems, Fairfield, CT) was performed on each skull. Image data were acquired in a 512×512 -pixel matrix and were electronically transferred to the StealthStation (Medtronic Surgical Navigation Technology, Louisville, CO). Stealth Cranial 2.6.4 software was used to reconstruct both coronal and sagittal images from the axial data. In addition, a three-dimensional (3D) model of the skull was constructed on the computer workstation. Each imaging dataset was analyzed in a systematic fashion that included identification of specific anatomic points (Table 1) and calculation of defined dimensions (Table 2). The surgical planning tools, which calculate position along planned surgical trajectories, were used for measurements. The corresponding anatomic points were also identified on each dried skull, and the corresponding measurements were completed on the skulls with scientific-grade calipers (Geneva Gage, Albany, NY). Because the data were paired observations, statistical analysis of the measurements was performed using

Table 1 Points Used in Measurements of Skull Base and Craniomaxillofacial Dimensions

Point	Definition
Palatine foramen	Palatine foramen (standard anatomic nomenclature)
Foramen spinosum	Foramen spinosum (standard anatomic nomenclature)
Anterior foramen magnum point	Most anterior point on the inner aspect of the foramen magnum
Posterior foramen magnum point	Most posterior point on the inner aspect of the foramen magnum
Interpalatine midpoint	Point located at the mid distance along a horizontal line between the right and left palatine foramina
Lateral foramen magnum point	Most lateral point on the inner aspect of the foramen magnum on each side
Lateral orbit point	Deepest point on the lateral curvature of the anterior orbit
Medial orbit point	Deepest point on the lateral curvature of the anterior orbit
Superior orbit point	Most superior point on the superior curvature of the anterior orbit
Inferior orbit point	Most inferior point on the inferior curvature of the anterior orbit
Zygomatic point	Point located at the greatest curvature of the outer zygoma

a paired Student's *t*-test, with statistical significance defined as a *P*-value of <0.05 .

RESULTS

The results are summarized in Table 3. Figures 1 to 3 demonstrate representative measurements obtained at the computer workstation. The differences in measurements obtained with scientific-grade calipers and CT review on a computer

Table 2 Definitions of the Parameters of Skull Base and Craniomaxillofacial Dimensions

Measurement	Definition
Interpalatine distance	Distance between the right and left palatine foramen points
Interspinosum distance	Distance between the right and left foramen spinosum points
Skull base length	Distance between the posterior foramen magnum point to the interpalatine midpoint
Foramen magnum AP distance	Distance between the anterior foramen magnum point and the posterior foramen magnum point
Foramen magnum transverse distance	Distance between the right and left lateral foramen magnum points
Intermedial orbit distance	Distance between the left and right medial orbital points
Interlateral orbit distance	Distance between the left and right lateral orbital points
Left orbit height	Distance between the left superior and inferior orbital points
Right orbit height	Distance between the right superior and inferior orbital points
Interzygomatic distance	Distance between the left and right zygomatic points

AP, anteroposterior.

workstation were not statistically significant for any of the anatomic points studied, with *P*-values ranging from 0.06 to 1.0. The difference in measurement for the right orbit height, the anatomic point with the smallest *P*-value, was only 0.24 mm. Differences between the calipers and the CT were insubstantial as well as insignificant.

DISCUSSION

This preliminary study confirmed that computer-enabled CT review and standard scientific-grade calipers provide similar measurements of skull base and craniomaxillofacial skeleton measurements, in the sense that differences between the measure-

Table 3 Caliper and Computer-Enabled CT Review Measurements of Skull Base and Craniomaxillofacial Dimensions

Item	Caliper (mm)	Computer-Aided CT Review (mm)	<i>P</i> -value
Interpalatine distance	33.36	33.64	0.255
Interspinosum distance	61.76	61.51	0.714
Skull base length	80.40	80.59	0.349
Foramen magnum AP distance	33.52	33.58	0.468
Foramen magnum transverse distance	28.88	28.84	0.803
Intermedial orbit distance	24.86	24.86	1.000
Interlateral orbit distance	95.66	95.50	0.227
Left orbit height	34.08	34.26	0.399
Right orbit height	35.12	35.34	0.063
Interzygomatic distance	126.54	126.54	1.000

AP, anteroposterior.

Figure 1 Identification of left palatine foramen. The dot (indicated by the arrow) indicates the location of the left palatine foramen. The corresponding CT slices in the orthogonal planes (i.e., coronal, axial, and sagittal) through this point are shown. The pointer on the 3D model also indicates the position. The software package also provides relative coordinates for this point in the imaging volume.

ments are not statistically significant. Although this conclusion seems intuitive, the computer-based CT models do contain sources of error that theoretically may invalidate the accuracy of measurements. For instance, the software protocols for reconstruction of the coronal and sagittal images as well as the 3D model (from axial data) may contain

inaccuracies that may distort anatomic relationships. Because most of the image data are calculated, rather than actual, it may be inappropriate to assume their intrinsic accuracy. Furthermore, the imaging data set must be sufficient to support precise computer-based modeling. In this study, 1-mm contiguous CT images were used. If thicker

Figure 2 Measurement of interpalatine distance. Both the left and right palatine foramen have been identified. One of these points was then chosen as an entry point, and the second point was selected to be the target point in the surgical planning mode. The trajectory between these points is shown. The software can calculate the distance of this trajectory. (When viewing the trajectories plotted by the surgical planning mode, it is important to realize that the trajectory lines depicted in each CT slice represent the isolated vector component for that plane, and not the true trajectory.)

Figure 3 Measurement of skull base length. The interpalatine distance has been determined. The halfway distance between these points was then selected. The coordinates of this point were then determined by passing along the surgical plan trajectory for the desired distance. This halfway point was then chosen to be the entry point for the surgical plan. The target point at the posterior foramen magnum point was chosen. The software calculated the distance between the target and entry points.

and/or noncontiguous CT slices were used, the image reconstructions would most likely suffer. For these reasons, validation of computer-enabled CT review is necessary.

During the planning of this project, it became apparent that the current approaches for the analysis of skull base and craniomaxillofacial dimensions are deficient in several respects. Although traditional cephalometrics based on plain-film radiographs is well standardized,¹⁻³ paradigms for standardized analysis of CT data are not yet available. Furthermore, computer workstation review of CT data provides perspectives that traditional cephalometrics does not; consequently, new parameters for computer workstation CT review were defined. The parameters (including anatomic points specified in Table 1 and derived measurements specified in Table 2) were adapted from projects in which CT models and stereolithographic models were compared⁴ and in which skull base landmarks were used to assess skull base growth.⁵ Admittedly, the parameters for this project were chosen somewhat arbitrarily; however, at the very least, they serve to support the hypothesis that computer workstation review of thin axial CT data can provide accurate information.

Although the precise clinical value of relationships presented in Table 2 has not yet been determined, it is anticipated that these parameters will prove helpful during skull base and craniomaxillofacial surgery. For example, measurements of left and right orbit height, intermedial orbit distance, and interlateral medial orbit instance may guide orbital reconstruction. Similarly, the interzygomatic distance may be useful for reduction of orbitomaxillozygomatic fracture. It should be emphasized that the computer workstation data presented in this article were obtained using the StealthStation software, whose primary focus is intraoperative stereotactic surgical navigation. Although the StealthStation is not currently optimized for craniomaxillofacial surgery, it is easy to conceive of modifications of currently available CAS systems so that CAS may guide craniomaxillofacial surgery. A few preliminary reports describing CAS in craniomaxillofacial surgery have already appeared.⁶⁻⁹

In many ways, this project represents further development of concepts that are currently well developed for plain-film cephalometrics.¹⁻³ Indeed, the paradigm of computer-enabled CT review may overcome limitations intrinsic to current cephalo-

metrics. Although cephalometrics is widely accepted for surgical planning for maxillofacial, orthodontic, and orthognathic surgery, its limitations must be recognized. Identification of landmarks on the lateral x-ray film is a recognized source of error^{10,11}; secondary errors result from inaccurate choice of landmarks.¹² Standard x-rays also produce enlargement of the resultant radiographic images; however, standardized techniques serve to minimize the practical impact of this problem.¹³ Finally, cephalometric images are planar; projections of complex 3D structures onto a 2D planar surface produce additional distortion.¹⁴

Computer-enabled review of CT images provides additional anatomic information; 3D models and planar images (in the orthogonal planes) inherently contain more precise anatomic information than do 2D projections of 3D structures. For this reason, identification of landmarks may be more precise. CT imaging does not produce artifacts of enlargement, produced by the divergence of incident x-ray beams used in plain-film radiography, as CT techniques produce direct tomographic images.

The paradigm of computer workstation review of CT imaging data also offers additional advantages. First, CT imaging is widely available and has demonstrated clinical value. In addition, advances in computer workstation technology have reduced the costs associated with these systems and enhanced their image-processing power. Further technologic improvements may be safely anticipated. Of course, computer workstations permit "virtual" anatomic dissections—avoiding the expense and hassles of traditional anatomic dissections.

This project also highlighted several disadvantages and challenges. The selection of cranio-metric landmarks was surprisingly difficult because not even a consensus on such landmarks has emerged. Although the StealthStation was adapted to this project, the software has not been optimized for this type of application.

It is anticipated that computer-enabled CT review will continue to garner additional interest as computer workstations become more available and

more powerful. As additional experience with these systems is gathered, the paradigm described in this project will likely undergo further modification. Although these systems may be widely adopted, it may be inappropriate to assume that their accuracy is reliable. In this project, the computer workstation review of CT images correlated well with corresponding measurements obtained with standard scientific calipers. These confirmatory results suggest that additional efforts in this area are warranted.

CONCLUSIONS

Computer-enabled review of CT data provides accurate measurements of skull base and craniomaxillofacial dimensions. In this project, differences in measurements obtained by computer workstation review of CT data and by standard scientific-grade calipers were not statistically significant. Computer-based CT image analysis offers significant advantages over traditional cephalometrics and anatomic dissection. This approach provides additional anatomic information and may be incorporated into computer-aided surgery applications for craniomaxillofacial and skull base surgery. Because of technologic developments, rapid advances in computer-enabled CT review are likely.

NOTE

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