A Comparative Study of Digital and Anatomical Techniques in Skull Base Measurement

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This study compared the accuracy of measurements of the skull base made using computed tomography (CT) images and an image-guided surgery system with those made using scientific callipers in order to evaluate the practicability of replacing conventional direct anatomical measurements with digitized techniques in skull base surgery. Important bony landmarks and parameters were measured using the three different methods in 25 cadaver skull bases. No statistically significant differences were observed between the methods. Coefficient of variation calculations indicated that data obtained from CT images was the most stable. Digital methods of navigation have the potential to reflect individual skull base anatomical features more accurately than traditional group-based data, but it is important to assess their accuracy. This study demonstrated that CT imageology and image-guided surgery systems can provide accurate anatomical measurements. Digital methods are also more flexible and less variable, and may have wide applications in this field. Though not perfect, digital imaging is a promising tool for skull base surgery.

KEY WORDS: IMAGE-GUIDED SURGERY; SKULL BASE; APPLICATION ACCURACY

Introduction

The structures of the skull base are dense and complex; accurate intra-operative orientation is, therefore, of significant importance in surgery involving the skull base and requires clinical experience and expert skills as well as extensive knowledge of the related anatomy. Skull base or cranial base surgery became a multidisciplinary subspecialty in the 1980s.

Traditionally, the orientation of skull base surgery depended mainly on data concerning the anatomical parameters of some important skull base structures. These data were obtained by statistically analysing measurements made with scientific callipers from groups of anatomy specimens and so are of limited use in determining the individual anatomical features of a particular patient. In contrast, image-guided surgery may more accurately reflect the anatomical features of the patient, achieving a more accurate orientation and minimizing risk.

Intra-operative brain shift is the most serious problem that can compromise the accuracy of orientation and depreciate the...
value of an image-guided surgery system. This is less of an issue in skull base surgery, as fixed bony structures which do not shift at all during the operation, are used as landmarks. Thus, the image-guided surgery system may be more suitable for skull base surgery than for other neurosurgical operations.

The present study evaluated the accuracy of computed tomography (CT) imageology and image-guided surgery measurements of the skull base compared with anatomical measurements using scientific callipers.

Subjects and methods

SUBJECTS

The brain and cranium were removed from formalin-fixed cadaver skulls. The study protocol was approved by the Ethics Review Committee of Shandong University School of Medicine, Shandong, China.

STUDY ASSESSMENTS

Bony structures including the lateral semicircular canal (LSC), anterior semicircular canal (ASC), posterior semicircular canal (PSC), foramen ovale (FOV), foramen spinosum (FSP), hypoglossal canal (HYC) and internal acoustic pore (IAP) were exposed for measurement.

The skulls were scanned using a 16-slice CT scanner (Siemens Sensation 16, Siemens, Shanghai, China) (1.0 mm slices, 120 kV, 50 mA) and data were input into an image-guided surgery system (BrainLab, Munich, Germany) (Fig. 1). A z-Touch® laser pointer (BrainLab) was used to outline the patient’s facial features (nasion, forehead, and medial, superior and lateral rim of the orbits), which were added to the CT images by the computer. After the calculations were completed, a measure of goodness of fit was
Comparison of digital and anatomical skull base measurements

displayed, which is known as the root mean-square error (RMSE) or registration accuracy. Registration accuracy is a predictive error calculated automatically and reflects the degree of matching between the reconstructed three-dimensional (3D) image and the actual structure. In the majority of navigation systems, this error is the average precision relative to the central point of the 3D image.

The following distances were measured on each side of the skull base using anatomical measurement with scientific callipers (Fig. 2), CT imageology (using BrainLab software) (Fig. 3) and the image-guided surgery system (Fig. 4): the lateral border midpoint of the LSC to the medial border midpoint of the FOV; the superior border midpoint of the ASC to the medial border of the FSP; the superior border midpoint of the ASC to the lateral border of the IAP; and the lateral border midpoint of the PSC to the superior border of the HYC.

Application accuracy (target localization deviation) between the actual position and the position localized by the image-guided surgery system was assessed by placing the tip of the navigation pointer on a landmark in the CT image and comparing the position of the tip with the position in reality (Fig. 5). The following targets were used on each side of the skull base: the medial tip of the FSP, the lateral border of the IAP, and the lateral border of the LSC.

To calculate coefficients of variation, the distance between the two sides of the FOV on a particular skull were measured 30 times by two independent surgeons using each of the three measurement modes.

STATISTICAL ANALYSIS

Results were calculated as means ± SD. Data analysis was performed using the SPSS® statistical package, version 15.0 (SPSS Inc., Chicago, IL, USA) for Windows®. Normally distributed data were analysed using a paired t-test for dependent samples, and abnormally distributed data were analysed using the Wilcoxon matched-pairs signed-ranks test. A P-value < 0.05 was considered to be statistically significant.

Results

Anatomical, CT imageology and image-guided surgery.

FIGURE 2: Tools used in the anatomical measurement of the skull base
Comparison of digital and anatomical skull base measurements

The computed tomography image scan was three dimensionally reconstructed by BrainLab software; for any two structures localized in the proper plane, such as the foramen ovale (FOV) and the anterior semicircular canal (ASC) the BrainLab software automatically calculates the distance between them.

FIGURE 3: The computed tomography image scan was three dimensionally reconstructed by BrainLab software; for any two structures localized in the proper plane, such as the foramen ovale (FOV) and the anterior semicircular canal (ASC) the BrainLab software automatically calculates the distance between them.

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The mean application accuracy (target localization deviation) between the actual position of 150 target measurements and the position localized by the image-guided surgery system was $2.09 \pm 0.65$ mm (range $0.8 – 4.5$ mm). The coefficients of variation for measurements of the distance between the two sides of the FOV using the three methods are given in Table 2.

**Discussion**

In traditional skull base surgery, the localization of some unseen structures depends on group-based regional anatomical data gained from studies of cadaver specimens; however, this is insufficient to reflect accurately the anatomical features of particular individuals. The possibility of using digital information to provide more accurate data is

guided surgery system measurements were taken from 25 cadaver skulls; the findings are given in Table 1. The registration accuracy (predictive error for the degree of matching between the reconstructed 3D image and the actual structure) for the image-guided surgery system was $1.20 \pm 0.33$ mm (range $0.7 – 1.9$ mm). The mean error between the imageology and the anatomical measurements was $1.03 \pm 0.97$ mm, which was less than the mean estimated error of $1.92 \pm 1.60$ mm between group-based estimated data and anatomical measurement. None of the differences between the anatomical and the imageology measurements or between the anatomical and the image-guided measurements was statistically significant.

The mean application accuracy (target localization deviation) between the actual position of 150 target measurements and the position localized by the image-guided surgery system was $2.09 \pm 0.65$ mm (range $0.8 – 4.5$ mm). The coefficients of variation for measurements of the distance between the two sides of the FOV using the three methods are given in Table 2.

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FIGURE 4: The image-guided surgery system monitored the position of a navigation stick and recorded its co-ordinates. By directing the tip of the navigation stick at two structures in turn (A and B), the system automatically calculated the distance between two structures.

Target distance: 44.4 mm

FIGURE 5: Target localization deviation (application accuracy) between the actual position and the position localized by the image-guided surgery system was assessed by placing the tip of the navigation pointer on a landmark in the computed tomography image and comparing the position of the tip with the position in reality. The system can enable some unseen structures of the skull base to be localized by referencing individual image data.

Point distance: 6.1 mm
Comparison of digital and anatomical skull base measurements

Individual anatomical features can be converted to digital data, but it is important to assess the accuracy of such information. In the present study, anatomical measurements were compared with imageology measurements based on CT images; there were no statistical differences between the two sets of measurements, showing that imageology information accurately reflects individual anatomical features. The error between the imageology and the anatomical measurements was approximately 1 mm, which is less than the estimated error with group-based data, suggesting that imageology is more valuable in guiding surgery.

Used as a digital device, the image-guided surgery system can describe individual anatomical features by measuring important anatomical parameters. In the present study, there were no statistical differences between the anatomical measurements and those produced by the image-guided surgery system. Moreover, the image-guided surgery system has advantages compared with anatomical methods, including less manual operation and convenience of use. Image-guided surgery can enable the surgeon to localize some of the unseen structures of the skull base by referencing individual image data. Due to the effects of registration accuracy, target localization deviation (application accuracy) occurs between the actual position and the position localized by the image-guided surgery system, which has important clinical implications. In the present study, the mean application accuracy of 150 target measurements was 2.09 mm; this is a satisfactory result and is accurate enough for

### Table 1: Comparison of skull base measurements using the anatomical, computed tomography imageology and image-guided surgery system methods

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Anatomical (mm)</th>
<th>CT imageology (mm)</th>
<th>Image-guided surgery system (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LSC to FOV</td>
<td>37.74 ± 2.42</td>
<td>37.46 ± 2.54</td>
<td>37.95 ± 3.50</td>
</tr>
<tr>
<td>ASC to FSP</td>
<td>28.00 ± 2.24</td>
<td>27.81 ± 2.13</td>
<td>27.68 ± 2.85</td>
</tr>
<tr>
<td>PSC to HYC</td>
<td>34.28 ± 3.50</td>
<td>34.50 ± 3.39</td>
<td>34.75 ± 3.46</td>
</tr>
<tr>
<td>ASC to IAP</td>
<td>13.87 ± 1.61</td>
<td>13.75 ± 1.37</td>
<td>14.05 ± 1.82</td>
</tr>
</tbody>
</table>

Data are shown as mean ± SD. No statistically significant differences between the methods (P > 0.05). CT, computed tomography; LSC, lateral semicircular canal; FOV, foramen ovale; ASC, anterior semicircular canal; FSP, foramen spinosum; PSC, posterior semicircular canal; HYC, hypoglossal canal; IAP, internal acoustic pore.

### Table 2: Comparison of the coefficients of variation (30 measurements each) of the distance between the two sides of the foramen ovale carried out by two independent surgeons using the anatomical, computed tomography (CT) imageology and image-guided surgery system methods

<table>
<thead>
<tr>
<th>Surgeon</th>
<th>Anatomical</th>
<th>CT imageology</th>
<th>Image-guided surgery system</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surgeon 1</td>
<td>0.40</td>
<td>0.39</td>
<td>0.40</td>
</tr>
<tr>
<td>Surgeon 2</td>
<td>0.69</td>
<td>0.47</td>
<td>0.68</td>
</tr>
</tbody>
</table>
surgery. Many researchers have demonstrated that frameless stereotaxis and frame-based stereotaxis are similar in accuracy.\textsuperscript{10} – \textsuperscript{12} Frameless methods are more complex but also more flexible and may have wide applications in general neurosurgery. Some studies have reported an application accuracy of about 1 mm with an updated image-guided surgery system and new registration mode.\textsuperscript{13} – \textsuperscript{15} Although it may be a little difficult to pinpoint some small lesions, image-guided surgery with an application accuracy of 1 – 2 mm is reliable; this level of precision is similar to that seen with traditional anatomical methods and is accurate enough for skull base surgery. Accuracy of location could be further improved by the introduction of intra-operative CT or magnetic resonance imaging.\textsuperscript{16} – \textsuperscript{18}

The consistency of the three types of measurements was investigated by analysing the coefficients of variation for measurements of the distance between the two sides of the FOV made by two independent surgeons. For each surgeon, the coefficient of variation was smallest for the imageology measurements, while the coefficients of variation of the anatomical and the image-guided surgery system measurements were similar to the coefficient of variation for imageology. The imageology measurements might be expected to be the most consistent because fewer manual operations are involved than for the anatomical and image-guided surgery system measurements. It seems that the degree of manual intervention is an important factor in determining the variability of the measurements; therefore, measurements made using advanced digital skull base surgery systems with much less manual intervention should be more constant and reliable than those made using traditional methods.

Digital methods of navigation based on CT imageology and computer technology have the potential to reflect individual skull base anatomical features more accurately than traditional group-based data, but it is important to assess the accuracy of such images. In this study there were no statistically significant differences between the three sets of measurements, indicating that CT imageology and image-guided surgery systems can provide accurate anatomical measurements. In addition, theoretical research and studies of practical outcome and clinical application have shown the superiority of image-guided surgery and imageology in skull base surgery.\textsuperscript{19},\textsuperscript{20} Digital methods are also more flexible and less variable, and may have wide applications in this field. Though not perfect, digital imaging is a promising tool for skull base surgery.

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Conflicts of interest
The authors had no conflicts of interest to declare in relation to this article.

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