Effect of the skin shift on navigation accuracy in image-guided neurosurgery

Poster No.: C-0109
Congress: ECR 2011
Type: Scientific Exhibit
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Keywords: Intraoperative, MR, Neuroradiology brain, Surgery
DOI: 10.1594/ecr2011/C-0109

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Purpose

1. Neurosurgery (Malignant brain tumor)

During surgical resection of brain tumors, it is important to perform total resection of the tumor without damaging any normal tissue. Excessive resection of tumors near functional areas (e.g., motor area) of the brain may cause severe neurologic deficits. However, it is difficult to identify tumor boundaries with the use of an operative microscope only.

2. Neuronavigation

The development of neuronavigation systems in recent years has enabled surgeons to comprehend the positional relationship between tumors and normal tissue [1]. Therefore, navigation systems are very useful in the resection of tumors located near the functional areas [2,3].

3. Navigation accuracy

Accuracy of the neuronavigation is important. However, many factors can deteriorate the navigation accuracy during surgery [4]. Before craniotomy, the patient's head is secured to a head frame with head pins; this fixation may cause displacement of fiducial markers (a reference point of the navigation) and deteriorate the accuracy. We term this phenomenon skin shift. In this study, the extent of skin shift and its effect on navigation accuracy were determined by use of both preoperative magnetic resonance imaging (MRI) scans acquired before fixation and intraoperative MRI scans acquired after fixation.
Methods and Materials

1. Ethical aspect

The ethics board of the Nagoya University School of Health Science approved this study, and informed consent was obtained from each patient.

2. Patient

We evaluated the skin shift and the navigation accuracy in ten consecutive patients. The study comprised patients who had undergone tumor resection under the guidance of a navigation system between September 11, 2009, and December 4, 2009 (men, 4; women, 6; mean [±standard deviation; SD] age, 35.9 [±22.7] years; range, 3-72 years).

3. Experimental step

#Six fiducial markers were placed on the patient's scalp (forehead, temple, and mastoid) on the day before the surgery (Fig. 1a).

#3T MRI (MAGNETOM Trio; Siemens, Erlangen, Germany) was performed before the surgery. Only T1-weighted images (gradient-echo sequence with inversion recovery: repetition time, 1570 ms; echo time, 2.19 ms; inversion time, 800 ms; slice thickness, 1 mm; matrix size, 256 × 256; flip angle, 15°) were used in this study because fiducial markers can be visualized in these images.

#Before the start of surgery, the patient's head was fixed to the Sugita head frame with 4 head pins under general anesthesia. A skin shift occurred at this time: the positions of the markers changed in reference to the positions on the preoperative MRI scans (Fig. 2).

#After fixation, intraoperative T1-weighted images were acquired (gradient echo sequence: repetition time, 21 ms; echo time, 9 ms; slice thickness, 2 mm; matrix size, 256 × 160; flip angle, 40°). Intraoperative imaging was performed with 0.4-T MRI (APERTO Inspire; Hitachi Medical Co., Chiba, Japan)[5].

[Because the MRI scans were acquired after the skin shift, the marker positions in real space corresponded to those on the intraoperative images. We evaluated the navigation accuracy and the extent of the skin shift by using preoperative and intraoperative images.]

4. Extent of skin shift
To measure the extent of the skin shift, we used fusion images generated by integrating of preoperative and intraoperative MRI scans. The fusion images were prepared with use of the iPLAN software (BrainLAB AG, Heimstetten, Germany). The difference in the three-dimensional distance between the center of each marker between preoperative MRI and intraoperative MRI was measured by use of the fusion images (Fig. 3). We calculated the maximum, minimum, and mean values for the skin shift and the standard deviation. Using simple linear regression analysis, we also determined whether the extent of the skin shift was correlated with the distance between the head pins and the fiducial markers.

5. Navigation accuracy

To assess the effect of skin shift on navigation accuracy, we performed registration twice: first by using the preoperative MRI scans acquired before the head pins were fixed, and second by using the intraoperative MRI scans acquired after fixation. The steps of registration are as follows: (1) The operator registers the center of the fiducial markers as registration points by using the iPLAN software. (2) The fiducial markers positioned on the patient's scalp are replaced with registration sockets, but the marker plates are retained in the same positions (Fig. 4a-c). This center of the registration socket precisely locates the center of the fiducial marker. (3) Registration is completed by pointing the center of each registration socket by using a navigation pointer (Fig. 4c). This procedure aligns the actual positions of the fiducial marker with its corresponding positions depicted in image-space.

We measured the navigation accuracy in terms of the fiducial registration error (FRE) with use of the navigation system (Vector Vision compact; BrainLAB AG, Heimstetten, Germany). The FRE is the root-mean-square distance between the positions of fiducials in image-space and the corresponding positions of fiducials in real-space after the registration procedure [6]. To evaluate the navigation accuracy, we directed the pointer at the center of the registration sockets. Then, the screen of the navigation system displayed the distance from the tip of the pointer and the center of the fiducial marker (Fig. 4d).
Fig. 0: (a) Six fiducial markers are positioned on the patient's forehead, temple, and mastoid. (b) The positions of the fiducial markers in real space are determined with use of an infrared camera, and (c) those in image space are determined on MRI scans. Registration is performed by aligning of image-space coordinates with real-space coordinates, with fiducial markers as reference points.

Fig. 0: Fixation of the head pins leads to movement of the patient’s skin and displacement of the fiducial markers.

Fig. 0: The fiducial markers were displaced (dotted arrows).

Fig. 0: (a) Fiducial marker, marker plate, and registration socket. (b) The fiducial marker is positioned on the marker plate when MR images are acquired. (c) The fiducial markers are replaced with registration sockets for registration and evaluation of the navigation accuracy. (d) When the surgeons point to the center of the registration socket, the screen of the navigation system displays the distance from tip of the pointer and the center of the fiducial marker on axial, sagital, and coronal images. The distance is displayed on the monitor.

Results

1. Extent of skin shift

We measured the extent of skin shift in ten consecutive patients. The maximum extent of the skin shift was 13.1 mm, and the minimum, 1.3 mm. The mean (±SD) extent of the skin shift was 5.34 (±2.65) mm (Fig. 1). No significant correlation was observed between the extent of skin shift and the distance between the head pins and the fiducial markers (p > 0.05) (Fig. 2). We also evaluated the skin shift of each marker with respect to the patient position and the location of the fiducial markers (Fig. 3). The mean (±SD) skin shift values in the supine and prone positions were 5.04 (±2.42) mm and 5.98 (±2.94) mm, respectively. The mean (±SD) skin shift values for the fiducial markers on the forehead, temple, and mastoid were 4.84 (±2.10) mm, 5.16 (±2.95) mm, and 6.33 (±2.66) mm, respectively. But no significant difference was observed for any of these parameters (p > 0.05).

2. Navigation accuracy

The mean (±SD) value for the navigation accuracy based on preoperative MRI scans acquired before fixation was 4.06 (±2.25) mm, and that based on intraoperative MRI scans acquired after fixation was 2.51 (±1.32) mm (Fig. 4). The navigation accuracy based on intraoperative MRI was significantly higher than that based on preoperative MRI (p < 0.001).
Fig. 0: We evaluated the skin shift in ten consecutive patients. The maximum, minimum, and mean values of skin shift and the standard deviation were calculated by use of fusion images.

Fig. 0: No statistically significant correlation was observed between the two parameters (p > 0.05)


<table>
<thead>
<tr>
<th>Category</th>
<th>Subcategory</th>
<th>Maximum value (mm)</th>
<th>Mean (±SD) value (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Patient position</td>
<td>Supine</td>
<td>10.6</td>
<td>5.04 (±2.42)</td>
</tr>
<tr>
<td></td>
<td>Prone</td>
<td>13.1</td>
<td>5.98 (±2.94)</td>
</tr>
<tr>
<td>Position of the fiducial markers</td>
<td>Forehead</td>
<td>8.73</td>
<td>4.84 (±2.10)</td>
</tr>
<tr>
<td></td>
<td>Temple</td>
<td>13.1</td>
<td>5.16 (±2.95)</td>
</tr>
<tr>
<td></td>
<td>Mastoid</td>
<td>10.2</td>
<td>6.33 (±2.66)</td>
</tr>
</tbody>
</table>

Fig. 0: No significant differences were observed for each position and positions of the fiducial markers (Student's t test; p > 0.05).

**Navigation accuracy**

<table>
<thead>
<tr>
<th>Registration image</th>
<th>Mean (±SD) value (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Registration based on preoperative MRI</td>
<td>4.06 (±2.25)</td>
</tr>
<tr>
<td>Registration based on intraoperative MRI</td>
<td>2.51 (±1.32)</td>
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</table>

**Fig. 0:** The mean (±SD) values of navigation accuracy are shown. A significant difference was observed between the values obtained for registration based on preoperative MRI and those based on intraoperative MRI (Welch t test; p < 0.001).

Conclusion

Discussion and Conclusion

1. Discussion

The mean (±SD) value of the skin shift was 5.34 (±2.65) mm in ten patients; no significant correlation was observed between this value and the distance between the head pins and the fiducial markers (p > 0.05). We investigated whether the skin shift was influenced by the patient position and the position of the fiducial markers. Although no significant difference was observed for any of these parameters (p > 0.05), the extent of the skin shift was the greatest for the fiducial markers positioned on the mastoid (6.33 [±2.66] mm).

Surgeons often rotate the patient's head according to the location of the tumor before fixing the head pins. This alignment may result in a greater skin shift near the mastoid than at the other locations. These results reveal that the extent of the skin shift correlates not only with the position of the fiducial markers, but also with other factors such as the position of the patient's head. Future studies should investigate other factors that affect the navigation accuracy in a larger study population.

The navigation accuracy improved in the case of registration based on intraoperative MRI after fixation of the head pins because the positions of the markers in real space corresponded well with the positions on the intraoperative MRI scans. In addition, the results indicate that skin shift reduces the navigation accuracy. The results of this study confirm those of our previous phantom study [1].

Various factors influence the navigation accuracy in neurosurgery. Many other research groups have investigated several of these factors. Steinmeier et al. studied imaging modalities and the position of fiducial markers [4]. They reported that registration based on CT images was more accurate than that based on MRI, and use of the scattered fiducial configuration resulted in higher accuracy than did the use of the clustered fiducials configuration. Thus, the imaging modality used and the configuration and number of fiducial markers influence the navigation accuracy. Mascott et al. assessed the navigation accuracy with respect to the procedure used for registration. They reported that the accuracy of registration based on implanted cranial fiducial markers was greater than that of other registration procedures (e.g., surface-based registration and registration based on anatomic landmarks or adhesive fiducial markers) [7]. In addition, this study shows that skin shift is an important factor affecting the navigation accuracy. The actual extent of skin shift had not been investigated.

These results are useful for development of the navigation system, and surgeons must consider skin shift while performing image-guided surgery with use of a navigation
system. Since intraoperative MRI can eliminate the effect of skin shift, registration based on intraoperative images is ideal for appropriate navigation accuracy.

2. Conclusion

This study revealed the extent of skin shift that is possible during fixation and its effect on the neuronavigation accuracy. Skin shift occurs when the patient's head is secured by a head frame with head pins and evidently reduces the navigation accuracy. Intraoperative MRI performed after fixation can correct the effect of skin shift. Registration based on intraoperative MRI is very helpful for performing safe and appropriate surgery.
References


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