The Role of Image-Guidance Systems for Head and Neck Surgery

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Background: Although image-guidance systems have gained widespread acceptance for neurosurgical procedures, their role for extracranial surgery of the head and neck is yet to be defined.

Objectives: To describe the authors’ experience with image-guidance systems and to measure the effects of image-guided technology on the performance of minimally invasive otolaryngological procedures.

Design: Prospective cohort study.

Methods: Optical- and electromagnetic-based image-guidance systems were used during the performance of endoscopic surgery on patients with disease of the paranasal sinuses, orbit, skull base, and temporal bone (n = 79). Results were compared with those in control patients who underwent similar surgery without image guidance during the same period (n = 42).

Results: Intraoperative anatomical localization was accurate to within 2 mm at the start of surgery in all cases. Accuracy degraded by 0.89 ± 0.20 mm (mean ± SE) during the operative procedure. The use of an image-guidance system increased operating room time by a mean of 17.4 minutes per case (image-guidance group, 137.3 ± 6.0 minutes [mean ± SE]; control group, 119.9 ± 5.7 minutes; P = .006) and increased hospital charges by approximately $496 per case. Intraoperative blood loss (image-guidance group, 178.4 ± 18.0 mL [mean ± SE]; control group, 149.4 ± 20.1 mL) and complication rates (image-guidance group, 2.7%; control group, 4.7%) did not differ significantly between groups.

Conclusions: Image-guidance systems can provide the head and neck surgeon with accurate information regarding anatomical localization in cases with poor surgical landmarks caused by extensive disease or prior surgery; however, the use of such systems is associated with increased operative time and expense.


The advent of minimally invasive surgery of the head and neck has prompted the development of image-guidance systems to assist the surgeon with intraoperative anatomical localization. These systems use computerized tracking devices to monitor the position of endoscopic instruments relative to the patient’s anatomical landmarks. The location of these instruments is depicted on a real-time, 3-dimensional video display of the preoperative computed tomographic (CT) or magnetic resonance imaging (MRI) scan.

Initially developed for neurosurgical procedures that required head fixation in a stereotaxic frame, image-guidance systems have recently been introduced that allow for free head movement during surgery. These systems have been used for procedures involving the paranasal sinuses, skull base, and temporal bone. Surgery in these regions is particularly well suited for image-guidance applications because of the proximity to the orbit and cranial cavities, which demands a high degree of anatomical precision.

The present study demonstrates that image-guidance systems can provide the head and neck surgeon with accurate information regarding anatomical localization in cases with poor surgical landmarks caused by extensive disease or prior surgery. However, the use of such systems is associated with increased operative time and expense.

TABLE 1

<table>
<thead>
<tr>
<th>Procedure</th>
<th>Image-Guidance Group</th>
<th>Control Group</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Maxillary antrostomy</td>
<td>63% (50/79)</td>
<td>86% (36/42)</td>
<td>.01</td>
</tr>
<tr>
<td>Turbinate resection</td>
<td>29% (23/79)</td>
<td>50% (21/42)</td>
<td>.03</td>
</tr>
<tr>
<td>Revision procedures</td>
<td>8% (6/79)</td>
<td>15% (6/42)</td>
<td>.23</td>
</tr>
</tbody>
</table>

The results of this study suggest that image-guidance systems can provide the head and neck surgeon with accurate information regarding anatomical localization in cases with poor surgical landmarks caused by extensive disease or prior surgery. However, the use of such systems is associated with increased operative time and expense.

The objectives of this report are to describe the authors’ experience with image-guidance systems and to measure the effects of these systems on the performance of surgical procedures in the head and neck.
MATERIALS AND METHODS

The study population consisted of 121 patients who underwent endoscopic surgery of the head and neck by 4 surgeons at Massachusetts Eye and Ear Infirmary, Boston, from November 1996 through August 1997. Previously described image-guidance systems8 (Figure 1 and Figure 2) were used in 79 cases (49 women, 30 men; mean age, 46.2 years; range, 15-80 years). Fifty-five patients underwent surgery with an optical-based image-guidance system (LandmarX; Xomed, Jacksonville, Fla). Twenty-four patients had surgery performed with an electromagnetic-based system (InstaTrak; Visualization Technology Inc, Woburn, Mass). Forty-six (58%) of these image-guided surgical procedures were revision procedures. All patients in the image-guidance group underwent preoperative CT scanning according to previously described protocols.8 Charges generated by the Radiology Department for these scans did not exceed the costs for standard sinus CT scans.

The control group consisted of 42 consecutive patients who underwent endoscopic surgery of the head and neck without the use of an image-guidance system during the same period, by the same surgeons, and at the same institution. There were 26 women and 16 men (mean age, 47.3 years; range, 27-85 years). Eighteen (43%) of these non–image-guided surgical procedures were revision procedures.

Disease stage was assigned to all patients according to a previously described sinus CT staging system.11 Surgical indications included chronic rhinosinusitis (n = 115), fibrous dysplasia of the ethmoid or sphenoid bone (n = 2), optic neuropathy requiring optic nerve decompression (n = 2), and cholesterol cysts of the petrous apex requiring transsphenoid drainage (n = 2). Since the latter 6 cases involved extensive surgery and were all part of the image-guidance cohort (Table 1), they were treated as outliers and were excluded from calculations of blood loss and operating room time. All surgical procedures were performed with the patients under general anesthesia.

Operating room time was measured as the total number of minutes spent by the patient in the operating room suite. This value reflected anesthesia and surgery times, as well as time for the setup and operation of the image-guidance system, including placement of the patient headsets, calibration and registration of the handheld probes, and use of the system for anatomical localization throughout the procedure.

Expense calculations for the use of an image-guidance system were based on hospital charges of $182 and anesthesia charges of $56 for each 15-minute interval of operating room time at Massachusetts Eye and Ear Infirmary. Surgical charges were not included in this calculation since they are procedure-dependent and do not change with increased operating room time. No separate charges were billed by the hospital or surgeon for the use of an image-guidance system. All headsets and handpieces used in this study were reusable and therefore did not generate additional costs or charges.

Sustained accuracy data were obtained for 16 patients who underwent surgery with the optical-based image-guidance system. At the start of surgery, reference points were selected by the surgeon from 4 possible anatomical sites on the skin surface—the glabella, nasion, right malar eminence, and left malar eminence. The tip of the straight probe was placed on the selected site as marked with a pen to establish a reference point of 0 mm. This procedure was repeated 10 times for each anatomical site selected to measure the degree of error associated with placement of the tip of the handheld probe on a precise anatomical location. The entire process was then repeated during the middle and end of surgery to measure any system instability or anatomical drift that had occurred during the procedure. Because of the additional time required to perform these measurements, the 16 patients involved in the sustained accuracy portion of this study were excluded from calculations of operating room time.

Statistical analysis and calculations were performed with the Statistical Analysis System (version 6.12; SAS Institute, Cary, NC) on a SPARC Station 10 computer (Sun Microsystems, Palo Alto, Calif). Fisher exact tests or 2-sample t tests were used for the comparison of group parameters. Multiple regression models were used to compare outcomes while adjusting for potential confounders, including CT scan stage, revision surgery rate, and types of procedures performed. The protocol for use of the InstaTrak system was authorized by the Human Studies Committee of the Massachusetts Eye and Ear Infirmary.

Figure 1. Intraoperative view of the headset and probe for the optical-based image-guidance system. Light-emitting diodes attached to these devices are tracked by an infrared camera to monitor the location of the probe tip relative to the position of the patient’s head.
20-750 mL) and control (149.4 ± 20.1 mL; range, 25-600 mL) groups. Blood loss correlated with CT scan stage (P < .001), but not with revision surgery.

Registration of the image-guidance system provided anatomical localization accurate to within 2 mm at the start of surgery in all cases. This degree of accuracy was confirmed with visual verification of known anatomical landmarks by the surgeon at the start of each case. The amount of anatomical drift that occurred during the case ranged from 0.64 to 1.37 mm (mean ± SE, 0.89 ± 0.20 mm), depending on the anatomical reference site selected at the start of surgery (Table 5). The left malar eminence, glabella, and nasion were all found to be suitable sites for verification of sustained accuracy, with a mean ± SE degradation in accuracy of 0.72 ± 0.19 mm throughout the surgical procedure. The larger anatomical drift of 1.37 mm found at the right malar eminence was thought to reflect both the looseness of the skin in this location and the fact that the right side faced the surgeon, making it more susceptible to distortion from movement of the facial drapes during surgery. The error associated with the surgeon’s attempts to reproducibly place the probe tip on a given anatomical reference point is reflected in the SD of these measurements, which ranged from 0.29 to 0.40 mm, as shown in Table 5.
There were no intraoperative complications. All procedures were performed with the patients under general anesthesia, with no patients complaining of postoperative discomfort from wearing headsets during the operative procedure. Follow-up averaged 11.2 ± 2.6 (mean ± SD) months for the image-guidance group (range, 12.6-18.1 months) and 13.9 ± 2.4 (mean ± SD) months for the control group (range, 11.4-18.2 months). Postoperative complications were limited to 4 cases of epistaxis, 2 (3%) from the image-guidance group and 2 (5%) from the control group. For 1 patient from each group, postoperative bleeding was controlled with local cauterization and packing in the emergency department. The other 2 patients had rebleeding despite the use of packing and required endoscopic ligation of the sphenopalatine artery to control bleeding from the posterior remnant of a partially resected middle turbinate. The difference in complication rates between groups was not statistically significant.

**Table 3. Operating Room Time**

<table>
<thead>
<tr>
<th>Surgery</th>
<th>Image-Guidance Group</th>
<th>Control Group</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Patients</td>
<td>Time, Mean (SE), min</td>
<td>No. of Patients</td>
</tr>
<tr>
<td>Primary</td>
<td>30</td>
<td>136.9 (6.8)</td>
<td>24</td>
</tr>
<tr>
<td>Revision</td>
<td>43</td>
<td>137.7 (8.9)</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>137.3 (6.6)</td>
<td>42</td>
</tr>
</tbody>
</table>

**Table 4. Estimated Blood Loss**

<table>
<thead>
<tr>
<th>Surgery</th>
<th>Image-Guidance Group</th>
<th>Control Group</th>
<th>P</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>No. of Patients</td>
<td>Blood Loss, Mean (SE), mL</td>
<td>No. of Patients</td>
</tr>
<tr>
<td>Primary</td>
<td>30</td>
<td>149.3 (22.3)</td>
<td>24</td>
</tr>
<tr>
<td>Revision</td>
<td>43</td>
<td>198.7 (26.1)</td>
<td>18</td>
</tr>
<tr>
<td>Total</td>
<td>73</td>
<td>178.4 (18.0)</td>
<td>42</td>
</tr>
</tbody>
</table>

**Table 5. Sustained Accuracy Data**

<table>
<thead>
<tr>
<th>Site</th>
<th>No. of Patients</th>
<th>Accuracy, Mean ± SE, mm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Start of Surgery*</td>
</tr>
<tr>
<td>Glabella</td>
<td>13</td>
<td>0.36 ± 0.04</td>
</tr>
<tr>
<td>Nasion</td>
<td>12</td>
<td>0.29 ± 0.02</td>
</tr>
<tr>
<td>Left malar</td>
<td>10</td>
<td>0.34 ± 0.04</td>
</tr>
<tr>
<td>Right malar</td>
<td>11</td>
<td>0.40 ± 0.04</td>
</tr>
</tbody>
</table>

* Mean of the SDs of 10 measurements made at 4 anatomical sites at the start and end of image-guided surgery.
† Difference in the mean value of 10 measurements made at 4 different anatomical sites at the start and end of surgery.

In an era of heightened concern for both cost and effectiveness of medical care, the impact of new technology in the operating room setting must be carefully evaluated. A balanced consideration of both the beneficial and detrimental effects of each new technology is critical for defining its appropriate role. In this study, image-guidance systems were found to be highly accurate and relatively easy to use for surgical procedures of the head and neck; however, the use of such technology was associated with increased operative time and expense.

Both the optical-based and electromagnetic-based image-guidance systems provided anatomical localization with an accuracy of 2 mm or better at the start of surgery. By the conclusion of surgery, this accuracy had deteriorated by an average of 0.89 mm because of anatomical drift. This finding is similar to the mean accuracy of 2.28 mm reported in a series of 55 sinus surgical procedures performed with an electromagnetic-based system. Because image-guidance systems are most helpful when used to confirm the identity of large compartments within the sinonasal cavities rather than to distinguish margins of safety at the millimeter level, this degree of degradation in accuracy is not felt to be clinically important. The authors used the straight probe most often to confirm the identity of the exposed ethmoid roof or to verify that the sphenoid sinus had been entered rather than a large posterior ethmoid cell. The curved suction cannula attached to the tracking device was frequently used to demonstrate that an ostium that had been opened in the frontal recess led to the frontal sinus rather than an adjacent supraorbital ethmoid cell.

The use of the image-guidance system was found to increase the mean total operating room time by 17.4 minutes per case. Since this value includes the time required to set up, calibrate, and register the system before the start of surgery, the actual surgical time is not prolonged. Fur-
thermore, this value represents a mean; earlier cases took longer when operating room personnel were learning to use the equipment. Once the surgeon and nursing staff became familiar with the system, it was the authors’ experience that additional operating room time could be reduced to less than 10 minutes. Uncontrolled studies have reported additional time requirements ranging from 10 to 20 minutes for the setup and operation of similar image-guidance systems for head and neck surgery.3,9,10,12

Because of the additional operating room time associated with the use of an image-guidance system, hospital charges increased by approximately $496 per case when this equipment was used. This value does not reflect actual reimbursements, which are usually considerably lower because of managed care contracts. Any difference between hospital costs related to the use of the image-guidance system and reimbursements would have to be absorbed by the institution. All headphones and probes used for surgical procedures during this study were reusable. If disposable instrumentation were used, additional costs per case would be incurred. The calculated costs would also increase if the depreciated value of the image-guidance system were factored into the cost analysis.

Because of the increased time and expense associated with the use of image-guided technology, it is not recommended for routine surgery of the head and neck. Some authors have advocated its use for all endoscopic sinus procedures5,12; however, we prefer to use it for those selected cases that present the surgeon with the greatest technical challenge. The enhanced anatomical localization provided by image-guided systems was particularly valuable for cases with poor anatomical landmarks, such as revision surgical procedures and patients with extensive disease.

Image-guided surgery is well suited for those surgical procedures in which the patient’s bony anatomy is distorted because of the disease process. The 2 cases of endoscopic drainage of cholesterol cysts in the petrous portion of the temporal bone would have been particularly difficult without image-guidance technology. The posterior wall of the sphenoid bone to access these cysts was removed with greater reassurance to the surgeon and greater safety for the patient because the image-guidance system confirmed the anatomical location of the cranial cavity and adjacent carotid artery. In the cases of fibrous dysplasia resection and optic nerve decompression, image-guidance technology allowed the surgeon to monitor the depth of bone removal relative to the skull base and optic canal. Intraoperative x-rays or a c-arm could have provided similar information to the operating surgeon, but not with the resolution or convenience provided by current image-guidance systems.

Although the image-guidance systems were found to be relatively easy to use, difficulties were encountered during their clinical application related to the tracking technologies. For those systems that used a radiofrequency signal for localization, metallic objects in the surgical field caused signal distortion. To ensure their proper function, patients had to be placed on 2 mattresses to increase their distance from the metal operating table. In addition, instrument tables, anesthesia equipment, and other sizable metallic devices had to be positioned an appropriate distance from the surgical field. When using an optical-based system, it was necessary to maintain a clear line of sight between the infrared camera and light-emitting diodes mounted on the surgical instrument for the system to function correctly. Therefore, the surgeon had to hold the instrument with the light-emitting diodes uncovered and pointed in the direction of the infrared camera. Furthermore, operating room personnel and equipment could not be positioned between the patient’s head and the camera lens, which was generally located 6 feet above the head of the table.

Although a device that provides the surgeon with accurate information regarding anatomical localization might be expected to result in more effective surgery with improved clinical outcomes, the impact of image-guided technology on patient symptoms and quality of life was not addressed by this study. Furthermore, because the rate of intraoperative complications for minimally invasive surgery of the head and neck is low, any effect of image-guided surgery on such rates would require controlled studies with very large patient populations.

### Image-guidance systems are available that can provide otolaryngologists with precise anatomical localization during head and neck surgery. This information can be particularly valuable for those cases with poor anatomical landmarks caused by extensive disease or previous surgery; however, the use of this new technology is associated with increased operative time and expense.

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### REFERENCES