Intra-Operative MR Imaging with a C-Arm System and Rotating, Tiltable Surgical Table: A Time-Use Study and Preliminary Clinical Results

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Introduction
Surgical navigation is an important application for interventional MR imaging, with significant potential impact on surgical technique during the next decade and beyond (1-2). Preliminary findings suggest a role for intra-operative imaging in neurosurgical procedures (3-7). As our intra-operative MR program matures, this study was performed to evaluate the frequency and duration of imaging sessions performed during surgery, direct additional procedure time attributable to imaging, and proportion of surgical cases in which information provided by intra-operative MR changed surgical procedure or otherwise was deemed valuable by the operating surgeons.

Materials and Methods
Surgical MR imaging suite and equipment: A surgical suite was constructed to comply with all operating suite standards. The room included HEPA filtered positive pressure ventilation, regulation light intensity, ceiling-mounted gas columns, and MR imaging-compatible anesthesia and patient monitoring equipment. The surgical flooring was color-coded to allow ready identification of the 20 mT, 0.5 mT, and 0.15 mT field lines. A 0.2T imager (Siemens Open Viva, Erlangen, Germany) was installed, along with a prototype surgical table. This table would be positioned to place target tissue at the isocenter and then smoothly rotated to a 120-degree angle from the imager, placing the surgical field at less than 0.5 mT field. The table allowed a wide range of height adjustment and Trendelenberg and reverse Trendelenberg tilting.

Imaging was performed using a circularly polarized head coil, large multipurpose solenoidal coil, or a prototype sterilizable solenoidal coil with surgical pin head-fixation. This latter coil was developed and supplied by the Heidelberg Neurosurgical Research Group. Standard operating microscopes, electrocautery, cortical stimulator, and fiberoptic headlamps were used. Endoscopy, when used, was performed with MR-compatible scope, light source, camera, and LCD display (Minrad, Inc., Clarence, NY).

Subjects and Procedures: Forty-two patients (6-77 years of age) underwent Neurosurgical or ENT intervention with the entire surgical procedure performed in the MR imaging suite either prior or following prototype table availability. Surgical procedures included craniotomy (n=25), transsphenoidal pituitary resection (n=11), brain needle biopsy (n=3), intracranial cyst aspiration/injection (n=2), and skull base resection (n=1). Craniotomies were performed for resection of glioma (n=18), meningioma (n=3), craniopharyngioma (n=3), and arteriovenous malformation with hematoma (n=1).

Intraoperative sequences included FISP, 3D and 2D T1W FLASH, T1W SE and T2W TurboSpin Echo. Each obtained between 3 and 16 3-5 mm sections with 20cm FOV and 128-256x256 matrix. Imaging times varied from 14 seconds to 6 minutes per sequence. The time necessary to drape the head, reposition the coil (if necessary), position the patient’s head at the magnetic isocenter, and tune the system ranged from 30 to 90 s.

For craniotomies, each imaging session typically included contrast-enhanced T1W images (~2 minutes/set) in all three orthogonal planes, along with T2W images (~3 minutes/set) in a subset of cases. For trans-sphenoidal surgical imaging, each imaging session included T2W coronal and/or sagittal images (~5 minutes/set), and T1W 2D coronal images (~8 minutes/set); contrast-enhanced T1W coronal and sagittal images were also obtained during the final imaging set. Specific sequences used for other pathologies were more variable, depending upon the anatomy and imaging characteristics of each lesion on initial intra-operative or pre-operative images.

Data Evaluation
Each case was analyzed for number of imaging sessions during the surgical procedure, time of each imaging session, impact of imaging information on surgical procedure, and total time spent on imaging during surgery. Impact on surgical procedure was based on whether additional tumor resection was performed due to imaging findings. Note was also made when the surgeon decided no further resection was necessary based on images. Time of imaging session was divided into intra-op (more resection following imaging), and post-op (last imaging session of case). This division was made since the final session of each case included additional investigational sequences for academic pursuit rather than clinical need in certain types of procedures.

Results
Each patient underwent between 1 and 5 imaging sessions during and immediately following surgery. The mean time spent during each imaging session is noted in the table below.

<table>
<thead>
<tr>
<th>Procedure</th>
<th>N</th>
<th>Mean imaging sessions/case</th>
<th>Mean time Intra-op Session (minutes)</th>
<th>Mean time Post-op session (minutes)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Craniotomy</td>
<td>18</td>
<td>3.2</td>
<td>14.9</td>
<td>13.1</td>
</tr>
<tr>
<td>Glioma</td>
<td>18</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Meningioma</td>
<td>3</td>
<td>3</td>
<td>19.3</td>
<td>17</td>
</tr>
<tr>
<td>Craniopharyngioma</td>
<td>3</td>
<td>2</td>
<td>16</td>
<td>21</td>
</tr>
<tr>
<td>AVM/hematoma</td>
<td>1</td>
<td>3</td>
<td>22.5</td>
<td>15</td>
</tr>
<tr>
<td>Transsphenoidal</td>
<td>11</td>
<td>3</td>
<td>12.7</td>
<td>24.7</td>
</tr>
<tr>
<td>Skull base</td>
<td>1</td>
<td>4</td>
<td>5.3</td>
<td>12</td>
</tr>
</tbody>
</table>

Mean total time spent on imaging per case for all cases noted above was 45.8 minutes. Imaging for brain biopsy and cyst aspiration/injection was continuous during the procedures, and averaged 81 and 53 minutes of total imaging time, respectively. Evaluation of the impact of imaging on surgery revealed additional surgery performed due to residual resectable tumor in 88% of cases.

Conclusions
Intraoperative MRI impacted the surgical procedure in a high proportion of cases, predominantly through the detection of residual tumor in resectable anatomic locations. With the rotatable surgical table, frequent intermittent imaging sessions were possible and allowed repeated assessment of resection completeness during surgery with otherwise conventional neurosurgical technique and instrumentation. Total additional time spent for imaging averaged less than 46 minutes per case despite multiple intermittent imaging sessions per case, and was not considered prohibitively long in the context of the types of cases performed.

References