Technical Note

Intra-Operative MR Guidance During Trans-Sphenoidal Pituitary Resection: Preliminary Results

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The use of intra-operative MR image guidance has the potential to improve the precision, extent, and safety of trans-sphenoidal pituitary resections. The trans-sphenoidal approach to pituitary surgery has been performed for some time (1–3). Until now these surgeries have relied on direct visualization without the aid of image guidance. An open-bore configuration 0.5T SIGNA SP MR system (GE Medical Systems, Milwaukee, Wisconsin) has been used to provide image guidance for seventeen trans-sphenoidal pituitary adenoma resections (4). The intra-operative MRI system allowed the radiologist to successfully direct the surgeon toward the sella turcica while avoiding the cavernous sinus, optic chiasm and other critical structures. Imaging performed during the surgery monitored the extent of resection and allowed for removal of tumor beyond the surgeon’s view in seven cases. Dynamic MR imaging was used to distinguish residual tumor from normal gland and postoperative changes, permitting more precise tumor localization. A heme-sensitive long TE gradient echo sequence was used to find the presence of hemorrhagic debris. All patients tolerated the procedure well without significant complications. J. Magn. Reson. Imaging 2001;13:136–141. © 2001 Wiley-Liss, Inc.

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Since its description in 1987 by Griffith and Veerapen (1), the direct trans-nasal, trans-sphenoidal approach to the pituitary fossa has become the procedure of choice for pituitary adenoma resection. Compared to other approaches to the sphenoid sinus (transethmoidal, sublabial trans-septal, and trans-antral), the direct trans-nasal approach offers straightforward access to the pituitary fossa with minimal nasal dissection and a reduced incidence of dental and septal problems. Despite these advantages, potential pitfalls exist. The shallow angle of approach can restrict access to supra-sellar lesions, and the size of the nasal cavity may limit the opening of the speculum, decreasing the extent of exposure (2). An endonasal, endoscopic trans-sphenoidal technique (3) has been used to enhance visualization, although this has the limitation of not allowing the surgeon to see beyond the exposed surfaces. Intra-operative MR image guidance allows the surgeon to see beyond the surface anatomy. At Brigham and Women’s Hospital, an open bore configuration 0.5T MR system with a 56 cm vertical gap (4) has been used, and since 1996, more than 350 open neurological procedures have been performed since 1996. The first MR guided trans-sphenoidal pituitary resection was performed in May of 1997, and seventeen procedures have been performed to date. We describe our preliminary results in assessing the feasibility of intra-operative MR for use in pituitary adenoma resection.

Materials and Methods

The open bore configuration the 0.5T SIGNA SP MR system (GE Medical Systems, Milwaukee, Wisconsin) (4) was used to provide intra-operative image guidance for seventeen trans-sphenoidal pituitary adenoma resections. The “double doughnut” with its vertical opening permits access to the patient, introduction of an operating microscope, and scanning in the same position without moving the patient. This allows frequent intra-operative scanning without significant delays. The MR interventional suite was designed to function as a fully equipped operating room (5) with all the necessary equipment within the bore of the magnet (Fig. 1). This includes all the surgical instruments, the surgical headlamps (Luxtec®), the bipolar cautery device (Codman®), and the operating microscope with a 250mm lens (Smed®). As generalized anesthesia was also necessary, MR-compatible anesthesia equipment, including an XL10 MRI compatible anesthesia station (Omelda; Madison, Wisconsin) and monitoring equipment

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systems (Maglife ODAM; Bruker, Wissembourg, France), were used (6).

After intubation the patient was positioned supine within the bore of the magnet, and the surgeon and an assistant stood across from one another within the vertical gap (Fig 2). A 5-inch, flexible loop, transmit-receive surface coil was placed over the patient’s face, and the head was positioned to allow for optimal imaging and surgical access within a 30-cm diameter spherical volume from the isocenter of the magnet. Imaging was controlled via the console just outside the MR interventional suite. Images obtained were simultaneously viewable on two 5-inch liquid crystal display (LCD) monitors mounted within the gap of the magnet (Fig. 2). Communication between the surgeons and the neuroradiologist was achieved through the use of small microphones mounted on the LCD monitors.

Imaging was performed immediately preoperatively, at several intervals during the resection, and immediately postoperatively. The preoperative imaging consisted of T1-weighted spin echo sequences in the sagittal and coronal planes (TR/TE 500/20, FOV 24 × 18, matrix 256 × 192,2 NEX, 5mm thickness). Similar T1-weighted sequences were performed both intraoperatively and immediately postoperatively. Dynamic imaging was performed after injection of a bolus of 20 cc of 0.5-mol/L solution of gadopentetate dimeglumine, using a two-dimensional fast spoiled gradient echo (FSPGR) sequence (7) (TR/TE 15.5/5.2, 45° flip angle, 22-cm FOV; 256 × 128 matrix, 1 NEX). The volume of interest covered the sella with six 5-mm-thick sections (0-mm interslice gap) imaged every 11 seconds for a total of nine repetitions. A special heme-sensitive gradient echo sequence with a TR of 600, varying TE values (9/40/60), and a flip angle of 30° was used to determine the presence of acute/hyperacute hemorrhage. This sequence could be performed during the resection as well as immediately postoperatively, depending on the clinical situation.

RESULTS

Seventeen patients (ages 14–77 years) underwent trans-nasal, trans-sphenoidal pituitary resection in the MR interventional suite between May 1997 and February 2000. Eight of the seventeen patients underwent primary surgical resections, and nine patients were referred from outside institutions with residual or recurrent lesions. In all but one of the cases, the final pathology identified tissue consistent with pituitary adenoma. No tumor cells were found in the case of re-operation after a total hypophysectomy six months earlier, and...
the surgical specimen demonstrated normal pituitary gland, fibrous scarring, and chronic inflammatory cells.

Preoperative T1-weighted spin echo sequences in the sagittal and coronal planes were used to guide the initial approach to the lesion via the trans-nasal, trans-sphenoidal approach. Figure 3 demonstrates immediate preoperative T1-weighted images that localize a lesion within the region of the sella turcica. The location of the lesion in relation to the optic chiasm, the pituitary stalk, and the sphenoid sinus is clearly seen. Intraoperative sagittal T1-weighted spin echo sequences were performed at intervals during the surgery to guide the surgical approach via the sphenoid sinus. The angle of approach and trajectory of the nasal speculum (Hardy® MR-compatible speculum) within the nasal cavity was evaluated. Serial imaging was performed to demonstrate the extent of the surgical resection (Fig. 4). The surgical approach thus obtained resulted in optimal tumor resection while avoiding the cavernous sinuses, optic chiasm and other sensitive structures.

After the lesions were partially resected, a dynamic sequence was performed to evaluate the extent of residual lesion (Fig. 5). Early enhancement indicated a normal pituitary gland, and delayed enhancement correlated with the presence of residual macroadenoma. These data were of great help to the surgeon, who was able to further explore the surgical bed and remove residual tumor.

After completion of the surgery, a final set of T1 sagittal images was performed followed by a heme-sensitive image sequence to evaluate for evolving hematoma. This gradient echo sequence was performed at TE values of 9, 40, and 60 msec. On short TE value, gas and metallic objects demonstrate loss of signal, while hyperacute/acute hemorrhage was isointense to the surrounding soft tissues. As the TE was lengthened, progressive blooming effect was noted in regions of acute hematoma formation. The usefulness of this sequence

**Figure 3.** Preoperative T1-weighted coronal and sagittal images demonstrate a pituitary adenoma within the region of the sella. A. Coronal T1-weighted image shows the lesion (arrowhead), the optic chiasm (long arrow), and the pituitary stalk (short arrow). B. Sagittal T1-weighted image demonstrates the relationship of the lesion (arrowhead) to the optic chiasm (arrow) and the sphenoid sinus.

**Figure 4.** A. Sagittal T1-weighted image showing the position of the nasal speculum in relation to the lesion (arrow) and the sphenoid sinus (arrowhead). B. After partial resection, a small amount of residual lesion is identified (arrow).

**Figure 5.** The 2D FSPGR image (A) shows minimal early enhancement of the lesion (arrowhead) but strong enhancement on the delayed T1-weighted image (B). A second dynamic image (C) toward the posterior aspect of the sella shows only minimal peripheral enhancement of the lesion (arrowhead) on both the early dynamic image and the delayed T1-weighted image (D). Note the strongly enhancing pituitary stalk (arrow) on images C and D.
is exemplified in a patient in whom hematoma was detected within the surgical cavity after completion of the resection [Figs. 6–9].

In all cases, the intraoperative MR system was successful in providing navigation to the lesion and identifying the proximity to critical structures such as the optic chiasm and the cavernous sinuses. In seven cases, intraoperative imaging identified additional residual tumor beyond the view of the surgeon, which was then explored and resected. A case where intraoperative MR truly demonstrated its utility involved a lesion invading the cavernous sinuses. As the surgeon removed tumor from the medial border of the left cavernous sinus, brisk hemorrhage was encountered. Immediate imaging demonstrated reduced flow through the left cavernous internal carotid artery, although the vessel remained patent with flow into the supraclinoid segment. Intraoperative image guidance allowed the surgeon to pinpoint his exact location so as to avoid further injury to the vessel, while being assured that distal blood flow was preserved. The patient went on to have follow-up studies, and recovered with no sequelae.

Of the seventeen patients who underwent trans-sphenoidal resection, twelve patients had an uneventful postoperative course and returned home shortly after surgery. Three patients developed trans-nasal leakage of cerebrospinal fluid shortly after surgery, requiring lumbar drain placement. One of these patients developed meningitis, and one patient developed a small postoperative hematoma seen on a follow-up head CT a few days after surgery which resolved without sequelae.

**DISCUSSION**

The particular challenges inherent in pituitary surgery include the limited access via the nasal passage and limited visualization of the location and depth of the target to be resected. Once access to the sella turcica via the trans-sphenoidal approach has been accomplished, the exact location of the lesion must be identified, and its relationship to neighboring vulnerable structures, such as the carotid artery and optic chiasm, must be assessed. Furthermore, assessment of hemorrhagic complications is crucial, since in this restricted surgical field, a small hematoma can develop significant pressure, causing optic nerve compression with resultant visual deterioration. With the use of intraoperative image guidance, the detection of an evolving hematoma can be made along with assessment of its size and location. The evaluation of the completeness of the resection is another issue which challenges current surgical technique. After the removal of the tumor, the surgical field is sealed to prevent CSF leaks by packing it with autologous muscle and fat transplant. This impairs the definitive post-operative assessment of surgical resection. Follow-up imaging for residual tumor is not ordinarily performed until six weeks after resection, since endocrinologic assessment is more accurate at that time. Intraoperative image guidance allows for im-

**Figure 6.** A. Sagittal T1-weighted image shows minimal fluid and debris within the surgical cavity (arrow). B. A midline sagittal image shows a clean surgical cavity extending into the suprasellar region where the tumor was previously present. The optic chiasm (long arrow) is shown, still mildly displaced along the superior aspect of the surgical cavity. The open sphenoid sinus (short arrow) is seen before surgical packing with fat.

**Figure 7.** A. T1-weighted sagittal image showing a hyperintense lesion in the region of the sella turcica (arrow) immediately before resection. B. The same lesion after partial resection.
mediate assessment of the surgical resection and identification of residual lesion, reducing the possibility of leaving tumor behind.

In patients who have had previous surgery, the normal anatomic landmarks may be distorted due to scarring. Postoperative changes along the approach through the sphenoid sinus and in the sella itself can make navigation to the residual/recurrent lesion difficult. The carotid arteries and optic chiasm may be displaced, making them more vulnerable to injury during the resection. However, the use of intraoperative image guidance allows the surgeon to make an immediate determination of the extent of residual tumor, the degree of postoperative scarring, and the relationship of the carotid arteries and the optic chiasm to the sella turcica.

Several methods for improving the safety and efficacy of trans-sphenoidal surgery have been developed using endoscopy, ultrasound, and frameless CT stereotaxis (3,10–12). MR imaging before and after trans-sphenoidal surgery has been described for the preoperative assessment of pituitary lesions and the postoperative evaluation of changes in the sellar region (9).

The use of intra-operative MR image guidance to direct the trans-nasal, trans-sphenoidal approach to pituitary adenoma resection allows for minimally invasive surgery with superior visualization of the lesion and its surrounding structures (13). Preliminary results have shown improved precision in tumor resection, particularly in cases in which there is suprasellar extension, by allowing the surgeon to see beyond the surface anatomy. The use of dynamic contrast-enhanced 2D FSPGR intraoperative image sequencing allowed residual tumor to be distinguished from normal pituitary gland, fibrosis, and postoperative changes, which was particularly helpful in patients who had previously had surgery. The safety of the procedure was optimized by allowing the surgeon to visualize the extent of surgical resection in relationship to sensitive nearby structures such as the optic chiasm and the cavernous sinuses. The use of heme-sensitive gradient echo imaging helped to distinguish evolving hematoma formation from residual tumor.

The recurrence rate of pituitary adenoma after resection was evaluated by Laws et al. (9), who published the largest series on trans-sphenoidal pituitary adenoma resection.
resection. Of the 2200 patients that underwent pituitary adenoma resection, 138 patients developed recurrence over a ten-year period. Although our results are preliminary, mainly assessing the feasibility of performing this surgery in the intraoperative MR, we have seen no recurrence in the patients in our series over a three-year period, based on imaging and clinical follow-up.

The implementation of an MR-compatible endoscope will further enhance the surgeon’s view of the surface anatomy (14, 15). In addition, several projects are under way to develop computerized image processing tools for both preoperative planning and real-time intraoperative image visualization (computer-assisted 3D interactive image guidance). Endoscopic and real-time MR images will thereby be displayed along with 3D reconstructed images to further improve the precision and safety of the procedure. Outcomes research should be performed to compare trans-sphenoidal surgery performed in the conventional operating room setting with that performed under intraoperative MR guidance.

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