Endoscopic Transsphenoidal Pituitary Surgery with Intraoperative Magnetic Resonance Imaging

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OBJECTIVE: The two most recent significant advances in pituitary surgery have been the endonasal endoscopic approach and intraoperative magnetic resonance imaging (IMRI). Each provides improved visualization of intra- and parasellar anatomy with the goal of attaining a complete resection. The combination of the two techniques has not been previously reported in the literature.

METHODS: We performed endoscopic, endonasal resection of pituitary macroadenomas in 15 patients using the Polestar N-10 (0.12T) IMRI (Odin Medical Technologies, Inc., Newton, MA). Eleven patients had nonfunctioning tumors, three had acromegaly, and one had a medication-resistant prolactinoma. The effect of the magnetic field on the cathode ray tube screen and the image quality of the IMRI images were assessed. The presence of residual tumor on IMRI was noted and then re-examined with the endoscope.

RESULTS: Although the Polestar N-10 is a low Tesla magnet, the IMRI caused significant distortion of the cathode ray tube screen regardless of the viewing angle. This was overcome with the use of a wall-mounted plasma screen. IMRI images were obtained in all cases and were of sufficiently high quality to demonstrate adequate decompression of the optic chiasm and the removal of all suprasellar tumor. In three cases, residual tumor was found with IMRI that was resected endoscopically before the completion of surgery. In four other cases, potential residual tumor was examined endoscopically and found to be normal postoperative change. In eight cases no residual intrasellar tumor was seen on the IMRI. Preresection visual deficits improved in all cases and the insulin-like growth factor levels normalized in two of three cases. There were no delayed cerebrospinal fluid leaks.

CONCLUSION: Combining intraoperative endoscopy and IMRI is feasible and distortion of the cathode ray tube screen can be overcome with the use of either a plasma or liquid crystal display screen. Each technology provides complementary information, which can assist the surgeon in safely maximizing the extent of resection. In this small series using a low-field magnet, rates of residual tumor following endoscopic transsphenoidal surgery were less than have been reported following microscope-based transsphenoidal surgery.

KEY WORDS: Acromegaly, Adenoma, Endoscope, Growth hormone, Intraoperative magnetic resonance imaging, Pituitary, Prolactin, Prolactinoma, Stereotaxis, Transsphenoidal

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Recent advances in surgical technology have had a major impact on the neurosurgical treatment for pituitary adenomas. Starting with the introduction of the transsphenoidal approach by Schloffer (25) and Cushing (8), in the early 1900s, followed by the addition of the operating microscope and fluoroscopy by Hardy (14) 60 years later, neurosurgeons have continued to attempt to make pituitary surgery less invasive and more effective. Arguably the two most important recent developments in this field are the endoscopic endonasal approach and the use of intraoperative magnetic resonance imaging (IMRI).

The endoscopic endonasal approach to the sella is performed with a rigid Hopkins rod endoscope advanced though the ostium of the sphenoid sinus without damaging the nasal mucosa. There is less postoperative swelling, nasal packing is avoided, patients are more comfortable postoperatively and most importantly, with the use of angled endoscopes, intrasellar visualization is dramatically improved as compared with the microscope (3–7, 12, 16–19, 24, 27, 28). The IMRI, on the other hand, offers improved visualization of residual tumor that may not be appreciated by the operating surgeon and has been shown to increase the extent of resection during microscopic transsphenoidal approaches anywhere from 33 to 66% of the time when surgeons take a "second look" at imaged residual tumor (2, 11, 20, 23).

The combination of these two innovative technologies has not been previously reported in a systematic fashion. There is definitely a learning curve to using endoscopic equipment within, or near, a magnet of sufficient strength for intraoperative imaging. In particular, we found that the magnetic field distorts the standard intraoperative CRT screen used to view the endoscopic images. We investigated the effect of the magnetic field on the cathode ray tube (CRT) screen and present our solution to this problem as well as report the first series of patients in whom a purely endonasal endoscopic approach was combined with intraoperative MRI in the treatment of pituitary adenomas and evaluate the impact of each technology on the surgical resection. Owing to the low field strength of our magnet, we have limited this series to macroadenomas.

METHODS

Inclusion Criteria

Patients included in this study had intrasellar mass lesions consistent with pituitary macroadenomas. Supradiaphragmatic extension was present in all patients, which ensured that the lesion would be clearly visible with the IMRI. Patients were candidates for transsphenoidal resection of their tumors based on clinical grounds (*Table 1*). Three patients had cavernous sinus invasion. Comprehensive endocrinologic and ophthalmologic evaluation was performed before surgery in all patients (*Table 1*). Two patients were previously resected via a transsphenoidal microscope-based approach (Patients 3 and 13), one of whom was radiated with stereotactic radiosurgery (Patient 13).

Surgical Procedure

The patient was orally intubated, a foley catheter, intravenous lines and MRI-compatible electrocardiography leads were placed and attached to an MRI-compatible anesthesia machine (Datex-Ohmeda, Madison, WI). The patient's head was fixed in neutral position, slightly elevated, in an MRI-compatible headholder (Medtronic, Minneapolis, MN) after placing a disposable surface coil (Medtronic) over the crown of the head, which was left in position during the surgery (*Fig. 1*). The nasal mucosa was vasoconstricted topically. Using a 0° 18-cm 4-mm rigid endoscope (Karl Storz, Tuttlingen, Germany), the sphenopalatine arteries and middle turbinates were injected with a mixture of lidocaine 1% and epinephrine (1:100,000). Under endoscopic view, the middle and superior turbinates were retracted laterally and the sphenoid ostia were identified bilaterally and enlarged. The posterior third of the nasal septum adjacent to the vomeric bone and maxillary crest was resected using a tissue shaver. This demonstrated a panoramic view of the sphenoid sinus rostrum and the ostia bilaterally. The mucosa of the sphenoid sinus rostrum was retracted laterally and the intersinus sphenoid septum was removed with a rongeur forceps. This brought the posterior

TABLE 1. Demographic data, presenting symptoms, extent of tumor removal and tumor immunostaining[a]

Patient no.	Age/sex	Tumor size (cm)	Symptoms	Hormone status	Extent of resection	Pathology and immunostaining
1	56/M	3.0 × 2.6	Visual loss	NL	Complete	Adenoma
2	47/M	2.6 × 2.3	Visual loss	NL	Complete	Adenoma (FSH+)
3	42/M	2.1 × 2.5	Acromegaly	↑ IGF-1, ↑ FSH	Complete	Adenoma (FSH+, GH+)
4	29/M	2.5 × 3.0	Visual loss	↑ FSH	Incomplete	Adenoma (FSH +)
5	30/F	2.2 × 2.1	Visual loss	NL	Complete	Adenoma
6	73/F	2.3 × 2.4	Visual loss	SIADH	Complete	Adenoma (PRL, FSH, LH+)
7	63/M	1.5 × 1.0	Acromegaly	↑ IGF-1, ↑ GH	Complete	Adenoma (GH+)
8	42/M	2.1 × 1.2	Visual loss	NL	Complete	Adenoma (FSH+)
9	57/F	3.0 × 2.4	Visual loss	NL	Complete	Adenoma (LH+)
10	67/M	2.5 × 3.0	Visual loss	NL	Complete	Adenoma
11	37/F	2.3 × 2.1	Amenorrhea	↑ PRL	Complete	Adenoma (PRL, FHS, GH+)
12	43/M	1.1 × 0.8	Acromegaly	↑ IGF-1, ↑ GH	Complete	Adenoma (GH+, FSH+)
13	52/M	2.3 × 1.5	CN VI palsy	↓ GH, ↓ T4	Incomplete	Adenoma, radiation change
14	46/F	3.2 × 4.1	Visual loss	MEN-1	Incomplete	Adenoma
15	52/F	1.2 × 1.1	Visual loss	NL	Complete	Adenoma

[a]NL, normal; FSH, follicle stimulating hormone; IGF-1, insulin-like growth factor; GH, growth hormone; LH, leutinizing hormone; SIADH, syndrome of inappropriate secretion of antidiuretic hormone; PRL, prolactin; T4, thyroid hormone; MEN-1, multiple endocrine neoplasia.

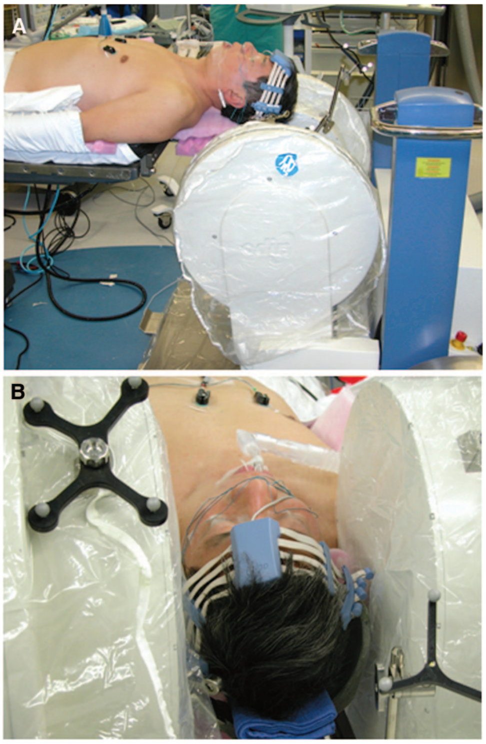

FIGURE 1. *Patient position in the IMRI for endonasal, endoscopic approach.* A, *the patient is supine with the magnet kept in reverse position below the patient's head. The disposable surface coil remains in place throughout the procedure.* B, *the reference frames for the magnet and patient's head face away from the head of the bed towards an infrared camera.*

wall of the sphenoid sinus in full view. Localization was confirmed with image guidance. A 0° 30-cm rigid 4-mm endoscope (Karl Storz) was introduced through the left nostril and held in place with a flexible scope holder (Karl Storz). Using the right nostril, the floor of the sella was opened with an osteotome or high-speed drill, curette and Kerrison rongeur. The dura was opened with a cruciate incision. The adenoma was identified and removed in a standard fashion using ring curettes. At the completion of the procedure, a 45° 18-cm 4-mm endoscope was used to examine the sella and suprasellar space for residual tumor.

After completion of the endoscopic surgical removal of the tumor, careful examination for cerebrospinal fluid (CSF) leak was carried out. Abdominal fat was harvested through a 3-cm incision in the anterior abdominal wall and was used to fill the sella. The floor of the sella was reconstructed with vomeric bone. Tissue glue was used to ensure a complete seal at the posterior wall of the sphenoid sinus. A lumbar drain was placed in all patients with significant intraoperative CSF leak. The middle turbinates were medially displaced before removal of the endoscope.

Intraoperative MRI

Before bringing the patient into the operating room (OR), the daily quality assurance and shimming were performed on the magnet. The OR was shielded to reduce radiofrequency noise and all electronic equipment were unplugged during quality assurance and subsequent image acquisition. The Odin Polestar N-10 IMRI was positioned under the OR table, beneath the head of the patient ("home" position) and was then robotically raised into "scanning" position (*Fig. 1*). The magnet reference frame and patient reference frame were placed in the line of sight of the infrared camera, which was placed at the head of the bed so as not to interfere with the surgical approach (*Fig. 2*). Preresection images of the sellar, parasellar, and nasopharynx were obtained before and after the administration of intravenous contrast (Gadolinium 0.6 cc/kg) and were subsequently used for stereotactic navigation during the endoscopic approach. The magnet was lowered under the bed during the surgical procedure. After the resection was complete, the magnet was raised to its preresection position, all electronic equipment were unplugged again and images were obtained before and after administration of intravenous contrast. Postresection images were compared with preresection images for the presence of residual tumor. If the images were felt to demonstrate residual tumor, re-exploration with the endoscope was performed suing stereotactic navigation to assess and remove any residual tumor.

Assessment of Image Quality

The distortion of the endoscopic images as displayed on the CRT screen was graded as either "unaffected" or "distorted" by the magnetic field of the IMRI (*Fig. 3*). The CRT screen was moved into several positions at a distance of 4 feet from the center of the magnet, where the screen would be comfortably

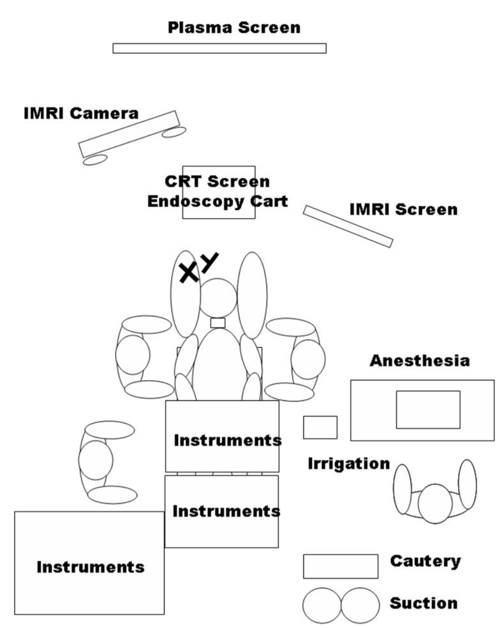

FIGURE 2. *Operating room set-up. The plasma screen is used for visualization since the magnetic field disrupts the CRT screen. X and Y represent the magnet and patient reference frames respectively, which must be in direct line of sight of the IMRI camera.*

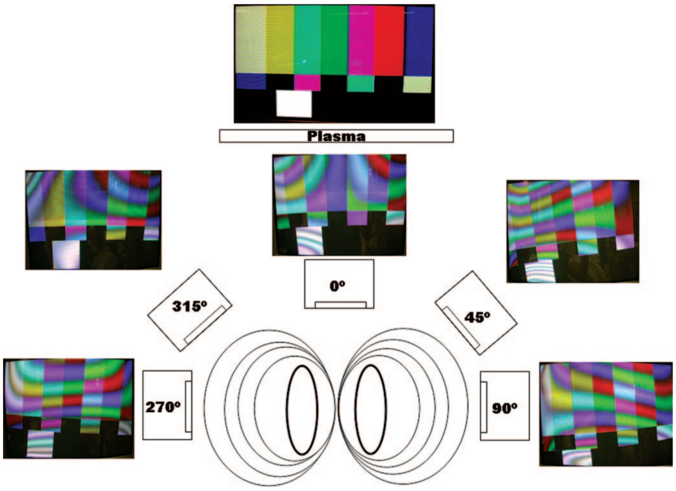

FIGURE 3. *Effect of the magnetic field on the CRT screen and plasma screen relative to the viewing angle.*

viewed during endoscopic surgery and the distortion was documented with a digital camera.

The quality of the IMRI images were graded as ″poor,″ ″useful,″ or ″excellent.″ ″Poor″ images, with little identifiable anatomy, were not usable; ″useful″ images were able to determine if the optic nerve was decompressed and that all suprasellar tumor was removed, but some image distortion or artifact might be present; ″excellent″ were images that could also detect residual intrasellar tumor and had little or no artifact.

RESULTS

Fifteen patients underwent combined endonasal, endoscopic transsphenoidal surgery within the intraoperative MRI (*Table 1*). Patient 3 had a previous microscope-based transsphenoidal resection with documented growth of the residual tumor on serial MRI scans and elevated insulin-like growth factor (IGF-1) as well as acromegalic body features. Patients 7 and 12 were also acromegalic. All other patients had progressive loss of vision. Patient 13 had previous microscope-based transsphenoidal surgery and stereotactic radiosurgery, and presented with a progressive sixth nerve palsy. Because the Polestar N-10 uses a 0.12 T magnet, we were able to use normal endoscopes and endoscopic equipment for the procedure. Titanium scopes were not necessary. The endoscopic equipment was unplugged during image acquisition. During our first surgery, it was clear that the magnetic field distorted the CRT screen and that this effect varied with the placement and orientation of the screen. Before our second surgery we investigated the relative relationship between the CRT screen and the magnet to see if we could eliminate this effect. The mean (standard deviation) duration of surgery was 280 ± 40 minutes, including imaging.

Endoscopic Image Quality

The CRT screen was rotated around the magnet which was placed in its ″home″ position underneath the OR table (*Fig. 3*). We found that, regardless of the orientation of the CRT screen, the magnetic field distorted not only the spatial homogeneity of the images, but also the color. For this reason, we abandoned the CRT screen and projected the endoscope images on a 42-inch plasma screen (Panasonic TH42PWD5; Matsushita Electric Industrial Co., Osaka, Japan) mounted on the wall of the OR using an S-video cord. The size of the screen and magnification of the image made the distance from the surgeons to the screen irrelevant and visualization was excellent. Using this screen there was no distortion and all images were ″unaffected,″ regardless of the distance from the magnet (*Fig. 3*). We have also found that liquid crystal display screens are unaffected by the magnetic field and are a less expensive alternative to a plasma screen.

IMRI Image Quality

In our earlier experience using IMRI after a standard microsurgical transsphenoidal approach, we found the titanium Hardy retractors (Codman/Johnson & Johnson, Raynham, MA) were poorly designed. Using standard Hardy retractors required removing and replacing the retractors for every image, which was not only tedious, but potentially damaging to the nasal mucosa. Using the endoscopic, endonasal approach, there are no retractors, facilitating the acquisition of IMRI images. The surface coil was placed at the beginning of the case and remained in the same position throughout the operation, which improved the image quality of the postresection images and facilitated comparisons with preresection images. The images were ″excellent″ in six patients and ″useful″ in nine patients (*Fig. 4*).

Outcome

There were no intraoperative complications. Residual tumor was identified in three patients using IMRI. A second look with the 45° endoscope confirmed the presence of tumor tucked behind the edge of the dura or within folds of arachnoid, which was resected. In four cases, the IMRI demonstrated possible residual disease that was not found with the endoscope and was thought to be either pooled blood or folds of arachnoid. In eight patients, no residual tumor was found on IMRI, except for expected disease in the cavernous sinus in three of these patients. Five patients had spinal drains placed prophylactically in the OR for significant intraoperative CSF leaks. Patients were followed for a mean of 6 months (minimum, 3 mo). Postoperative 1.5 T MRI scans were obtained immediately after surgery and at 3 months. All patients had evidence of complete removal of their intra- and suprasellar tumor, two of whom had expected residual tumor in the cavernous sinus. Patients were evaluated in the immediate postoperative period, at 1 week, 1 month and 3 months by an endocrinologist. Visual field abnormalities improved in all patients. Of the three patients with elevated IGF-1 and growth hormone levels, two had normal levels at the last follow-up examination (3 and 6 mo) and two patients developed transient diabetes insipidus requiring deamino-8-D-arginine vaso-

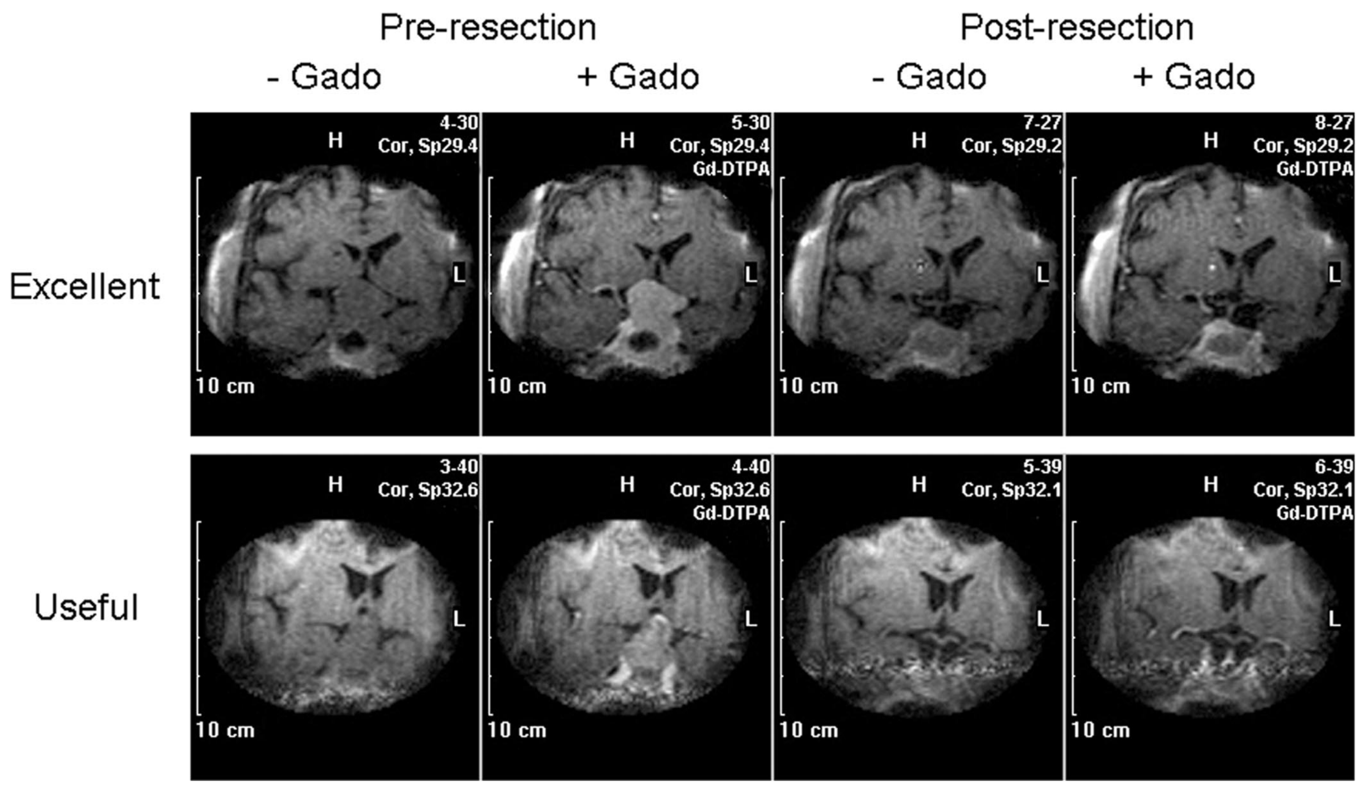

FIGURE 4. *IMRI images were classified as either "excellent" or "useful." Note that in the "useful" images, the optic nerves and stalk can be clearly seen in the postresection images, but there is some artifact causing a horizontal distortion across the bottom of the image.*

pressin, one of whom also required temporary steroid replacement. There were no delayed CSF leaks.

DISCUSSION

We report the first series of patients to undergo combined endonasal, endoscopic transsphenoidal surgery using intraoperative MRI for both navigation and assessment of extent of resection. Both techniques offer theoretical advantages in the surgical treatment of pituitary tumors and their combination is inevitable. Technical limitations have impaired the use of endoscopes within close proximity to the magnetic fields required for IMRI. Although titanium endoscopes are available, these are unnecessary when using a low Tesla magnet such as the Polestar N-10 (13). Nevertheless, even 0.12 T is sufficiently strong to interfere with the standard endoscopic CRT screen. We found that, regardless of the position of the screen, the magnetic field interfered with the images when kept within observable distance. At a higher field strength, the interference would be worse. Although it was possible to perform surgery in spite of the color distortions, a better solution was to mount a large plasma screen monitor on the wall of the OR or to use a liquid crystal display screen. We found no image distortion using these solutions. Using the combination of IMRI and endoscopy, we have found that each technique offers unique and complementary information.

Endonasal Endoscopic Approach

The purely endoscopic, endonasal approach to remove a pituitary adenoma was first reported by Jankowski et al. (17) in 1992 and then popularized by Jho and Carau (18), Cappabianca et al. (3–5), and others (6, 7, 12, 16, 19, 24, 27, 28). Advantages over the standard submucosal microscope-based approach include increased visualization of sphenoid and sellar anatomy leading to a reduction in CSF leak and an increase in extent of resection, elimination of nasal packing, preservation of sphenoid mucosa and mucocioliary transport and increase in postoperative patient comfort. Disadvantages are the lack of stereoscopic vision and limited maneuverability using the one nostril approach. We feel the two-nostril approach (24) used at our institution eliminates this latter limitation and the advent of stereoscopic endoscopes will eliminate the former. Moreover, by using both nostrils, two surgeons can introduce four instruments into the operative field in addition to the endoscope. Although most neurosurgeons still use a submucosal, microscope-based approach, the popularity of the endonasal, endoscopic approach is increasing. Long-term follow-up studies are lacking to show that the endonasal, endoscopic approach offers an advantage in completeness of resection but the improved visualization is unquestionable and likely identifies residual tumor unseen with the microscope, particularly when an angled scope is advanced into the sella to look laterally. For this reason, some surgeons perform a standard microscope-based submucosal or endonasal approach and then use the endoscope to identify tumor remnants before closure. In our small series, the endoscope was useful in differentiating actual residual tumor from postresection blood products demonstrated by the IMRI. We also report finding residual tumor in only three out of 15 (15%) of patients using IMRI, which is lower than is found after microscope-based resections (see below). Although our series is small, we attribute an increased extent of resection to the improved visualization provided by the endoscope.

IMRI

Several imaging modalities have been used to assist in intraoperative navigation and assessment of extent resection during transsphenoidal pituitary surgery including fluoroscopy (15), gas cisternography (21), computed tomographic scanning (22) ultrasonography (9), and frameless stereotaxy (10). IMRI was introduced into the practice of neurosurgery by Black et al. (1) at Brigham and Woman's Hospital in 1994. Since that time, several groups have reported on the efficacy of IMRI in the surgical treatment of pituitary adenomas (2, 11, 20, 23). Because MRI is currently the best noninvasive method for visualizing the relationship between the pituitary tumor and surrounding normal anatomy, the ability to have real-time MRI images during surgery is a valuable adjunct in assessing the extent of resection and preventing postresection hematomas. In the series by Pergolizzi et al. (23), using a 0.5 T magnet, seven out of 17 patients had residual tumor identified by IMRI, which was then resected during the initial operation. Fahlbusch et al. (11) used a 0.2 T magnet and although they only obtained adequate images in 73% of 44 patients, residual tumor was identified in 34% resulting in removal of additional tumor not appreciated during the initial resection. Bohinski et al. (2) reported 30 patients who were imaged using a 0.3 T magnet, of which 66% had residual tumor discovered with IMRI after initial resection. In all cases, the authors used an MRI-compatible speculum for retraction and a microscope for visualization.

In our study, residual tumor was discovered in only 15% of cases on the IMRI. This number is smaller than has been reported with microscope-based surgeries. In fact, these three cases occurred early in our series. Later, when our proficiency with the endoscopic technique improved and we became more aggressive about advancing angled scopes within and above the sella, we did not find residual tumor with the IMRI. Although we feel that the increased visualization provided by the endoscope permitted a more complete removal, it is also possible that the lower magnetic field strength was not sufficient to completely visualize residual disease. However, imaging at 3 months with a 1.5 T MRI did not reveal additional tumor missed with the lower field magnet. A larger series will be required to confirm this impression.

Advantages of the Combined Endonasal Endoscopic and IMRI Approach

We found that the advantages afforded by endoscopy and IMRI were non-overlapping when used in combination. In three of our patients, residual tumor was discovered by IMRI which was originally not appreciated during endoscopic resection, but was later confirmed with the endoscope. However, in four other patients, the IMRI overcalled the presence of residual tumor, and the absence of tumor was determined with direct endoscopic visualization. Certainly, endoscopy cannot see past opaque surfaces like IMRI. On the other hand, there is no substitute for direct visualization, particularly because postresection IMRI images can be ambiguous with low-field magnets. We found direct visualization to be better at differentiating residual tumor from postresection blood and artifact from hemostatic agents in the operative field. Thus, IMRI and endoscopy offered different and complimentary information. However, while low-field IMRI is generally only useful in ensuring removal of suprasellar tumor, the endoscope is useful for both intra- and suprasellar tumor.

Limitations

The image quality provided by a 0.12 T IMRI is not as clear as with higher-Tesla magnets (26). Hence, we have only found low-field IMRI helpful in visualizing suprasellar extension of macroadenomas. In addition, the limited field of view can be disorienting. However, we found the quality of the images to be adequate and clearly sufficient to determine the extent of resection of suprasellar tumor. Interpretation of intraoperative images can be challenging, similar to early postoperative images, since blood and hemostatic agents within the operative field can be misleading. Endoscopic procedures tend to require more meticulous hemostasis to improve visualization, which renders the intraoperative images easier to interpret. Whether image quality is sufficient with a low Tesla magnet to visualize small remnants of residual intrasellar tumor is unknown and will be the subject of a larger study. With the Polestar N-10, the field-of-view, although limited, was large enough to include the sellar, suprasellar, and nasopharyngeal spaces for navigation during the approach and resection. In addition, the use of the IMRI clearly added significant length to the operation. However, as the ancillary staff within the operating room became more familiar with the procedures required for intraoperative imaging, the time required decreased and the additional time under anesthesia did not appear to add incremental morbidity. Finally, because the follow-up period was limited in the preliminary report, the overall impact of these novel technologies on long-term outcome will clearly require more time.

CONCLUSIONS

We present our initial experience in combining IMRI and endonasal endoscopy for resecting pituitary macroadenomas. Although the magnetic field can distort the CRT images, the use of a plasma screen is a useful method for overcoming this distortion effect. From our preliminary experience, we feel that both IMRI and endoscopy offer unique and complementary advantages and the combination of IMRI and endoscopy will become the state of the art in pituitary surgery in the near future. In this small series using a low-field magnet, residual tumor was discovered less frequently on IMRI using the endoscopic approach compared with rates of residual tumor after microscope-based resections.

REFERENCES

1. Black PMcL, Moriarty T, Alexander EI, Stieg PE, Woodard EJ, Gleason PL, Martin CH, Kikinis R, Schwartz RB, Jolesz FA: Development and implementation of intraoperative magnetic resonance imaging and its neurosurgical applications. **Neurosurgery** 41:831–845, 1997.
2. Bohinski RJ, Warnick RE, Gaskill-Shipley MF, Zuccarello M, van Loveren HR, Kormos DW, Tew JMJ: Intraoperative magnetic resonance imaging to determine the extent of resection of pituitary macroadenomas during transsphenoidal surgery. **Neurosurgery** 49:1133–1144, 2001.
3. Cappabianca P, Alfieri A, de Diviitis E: Endoscopic endonasal transsphenoidal approach to the sella: towards a functional endoscopic pituitary surgery (FEPS). **Minim Invasive Neurosurg** 41:66–73, 1998.
4. Cappabianca P, Cavallo IM, Colao A, Del Basso De Caro M, Esposito F, Cirillo S, Lombardi G, de Diviitis E: Endoscopic endonasal transsphenoidal approach: Outcome analysis of 100 consecutive cases. **Minim Invasive Neurosurg** 45:193–200, 2002.
5. Cappabianca P, Cavallo LM, de Diviitis E: Endoscopic endonasal transsphenoidal surgery. **Neurosurgery** 55: 933–941, 2004.
6. Carau RL, Jho HD, Ko Y: Transnasal transsphenoidal endoscopic surgery of the pituitary gland. **Laryngoscope** 106:914–918, 1996.
7. Cooke RS, Jones RAC: Experience with the direct transnasal transsphenoidal approach to the pituitary fossa. **Br J Neurosurg** 8:19–22, 1994.
8. Cushing H: *Pituitary Body, Hypothalamus and Parasympathetic Nervous System.* Springfield, Charles C. Thomas, 1932.
9. Doppman JL, Ram Z, Shawker TH, Oldfield EH: Intraoperative US of the pituitary gland. Work in progress. **Radiology** 192:111–115, 1994.
10. Elias WJ, Chadduck JB, Alden TD, Laws ER Jr: Frameless stereotaxy for transsphenoidal surgery. **Neurosurgery** 45:271–277, 1999.
11. Fahlbusch R, Gannslandt O, Buchfelder M, Schott W, Nimsky C: Intraoperative magnetic resonance imaging during transsphenoidal surgery. **J Neurosurg** 95:381–390, 2001.
12. Gamea A, Fathi M, el-Guidy A: The use of the rigid endoscope in transphenoidal pituitary surgery. **Laryngol Otol** 108:19–22, 1994.
13. Hadani M, Spiegelman R, Feldman Z, Berkenstadt H, Ram Z: Novel, compact, intraoperative magnetic resonance imaging-guided system for conventional neurosurgical operating rooms. **Neurosurgery** 48:799–809, 2001.
14. Hardy J: Transsphenoidal hypophysectomy: Neurosurgical Techniques. **J Neurosurg** 34:582–594, 1971.
15. Hardy J, Wigsar SM: Transphenoidal surgery of pituitary fossa tumors with televised radiofluoroscopic control. **J Neurosurg** 23:612–619, 1965.
16. Heilman CB, Shucart WA, Rebeiz EE: Endoscopic sphenoidotomy approach to the sella. **Neurosurgery** 41:602–607, 1997.
17. Jankowski R, Auque J, Simon C, Marshal JC, Hepner H, Wayoff M: Endoscopic pituitary tumor surgery. **Laryngoscope** 102:198–202, 1992.
18. Jho HD, Carau RL: Endoscopic transphenoidal surgery: Experience with 50 patients. **J Neurosurg** 87:44–51, 1997.
19. Jho HD, Carau RL, Ko Y, Daly MA: Endoscopic pituitary surgery: An early experience. **Surg Neurol** 47:213–223, 1997.
20. Martin CH, Schwartz R, Jolesz FA, Black PMcL: Transphenoidal resection of pituitary adenomas in an intraoperative MRI unit. **Pituitary** 2:155–162, 1999.
21. Nesbakken R, Reinlie S, Eldevik OP: Intraoperiatve gas cisternography and gas dissection in the operative treatment of pituitary tumors. A methodological description. **Eur Surg Res** 16(Suppl 2):73–79, 1984.
22. Okudera H, Takemae T, Kobayashi S: Intraoperative computed tomographic scanning during transsphenoidal surgery: technical note. **Neurosurgery** 32:1041–1043, 1993.
23. Pergolizzi RSJ, Nabavi A, Schwartz RB, Hsu L, Wong TZ, Martin CH, Black PMcL, Jolesz FA: Intra-operative MR guidance during trans-sphenoidal pituitary resection: Preliminary results. **J Magn Reson Imaging** 13:136–141, 2001.
24. Rodziewicz GS, Kelley RT, Kellman RM, Smith MV: Transnasal endoscopic surgery of the pituitary gland: Technical note. **Neurosurgery** 39:189–193, 1996.
25. Schloffer H: Endoscopic transsphenenoidal pituitary surgery with intraoperative magnetic resonance imaging [in German]. **Weh Wein Klin Wochamschr** 20:621, 1907.
26. Schulder M, Liang D, Carmel PW: Cranial surgery navigation aided by a compact intraoperative magnetic resonance imager. **J Neurosurg** 94:936–945, 2001.
27. Shikani AH, Kelly JH: Endoscopic debulking of a pituitary tumor. **Am J Otolaryngol** 14:254–256, 1993.
28. Wurster CF, Smith DE: The endoscopic approach to the pituitary gland. **Arch Otol Head Neck Surg** 120:674, 1994 (letter).

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COMMENTS

Utilizing all possible means to maximize safe and complete pituitary tumor removal and avoid second surgeries or radiotherapy is certainly a reasonable surgical goal. The combined use of the panoramic endoscopic view with intraoperative magnetic resonance imaging (MRI) surveillance is a step in the right direction toward achieving this goal. The authors have nicely demonstrated the potential utility and some of the pitfalls of this technically challenging approach. Given the small number of cases in this retrospective series and the low field MR images, it remains unclear whether this approach is clearly superior over microscopic removal with subsequent intraoperative MRI. Further complicating any head-to-head comparison of intraoperative MRI studies is the potential bias inherent in these studies as to the definitive goals of the initial tumor removal. Given that the surgeons know they will be taking an intraoperative MRI, initial tumor removal may be less aggressive and less thorough than if intraoperative MRI was not available. This reality can provide a "self-fulfilling prophecy," whereby one is more likely to leave behind accessible tumor that would have been otherwise removed with either the endoscope or the microscope. Certainly, intraoperative MRI and endoscopy are here to stay and are undoubtedly very useful in select transsphenoidal cases. More studies such as this one with longer follow-up and higher field MRIs are needed to better delineate the utility of this combined approach.

Daniel Kelly
Los Angeles, California

The authors present a series of 15 patients with pituitary macroadenomas with supradiaphragmatic extension who underwent endonasal endoscopic approaches with intraoperative magnetic resonance imaging. They note that intraoperative magnetic resonance imaging (IMRI) images were obtained in all cases and were of sufficiently high quality to demonstrate adequate decompression of the optic chiasm and the removal of all suprasellar tumors. In three cases, residual tumor was found with IMRI that required resection. A second look with a 45° endoscope confirmed the tumor behind the edge of the dura or within folds of arachnoid. In four, abnormal signals on IMRI was found to be operative when examined endoscopically, and in eight, no residual tumor was noted. As they became more familiar with the procedures, they required less operative time, as one would expect, for intraoperative imaging. They suggest that combining intraoperative endoscopy and IMRI is feasible and provides complementary information. The caveat that the lower magnetic field strength of the Polestar may not be sufficient to completely visualize residual disease needs to be explored in a future study as well as its utilization for microadenomas. We have also found that a simple resolution to magnetic field abnormalities is the use of a plasma display.

Michael L. Levy
San Diego, California

The authors report their experience on a series of 15 pituitary macroadenomas treated with the combination of endoscopic transsphenoidal approach and low-field 0.12 IMRI. Employing these two technologies, residual tumor was found with IMRI in three cases and was removed endoscopically, while in four cases, IMRI demonstrated possible residual tumor, which was not found with the endoscope but was felt to be either pooled blood or arachnoid folded. Even if the patient series is small, the results of the study make possible to evaluate how the use of the endoscope reduces the false-positives of IMRI scan, thus reducing the disadvantages of the low-field MRI. Nevertheless, the potential risk of false negative interpretation of low-field IMRI is higher as compared to high-field IMRI, and, in fact, the authors have underlined that the benefits of low-field MRI are limited only to the suprasellar portion of the lesion. The advantages derived from the combination of this IMRI and endoscopy are clearly valuable with the extent of tumor removal reported. Larger patient series with longer follow-ups are expected to confirm if this imaging guidance system improves the outcome of the endoscopic transsphenoidal approach for pituitary macroadenomas. In conclusion, it seems that this low-field IMRI benefits large or giant macroadenomas when the surgeon cannot always estimate how much residual lesion has been left when using the endoscope to explore from the inside the lesion. Furthermore, it offers the fastest way to check the intraoperative occurrence of intracranial complications. The easy set-up of the intraoperative IMRI control, the relatively short time the control requires, and the costs of the instrument, surely are lower than the conventional IMRI and are true advantages that are not negligible with a cost-benefit analysis.

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Naples, Italy

Patent for Bipolar RF Generator. (Malis JL, Malis LI, Acorcey RR, Klaus HE, Solt DL, DiJoseph F, inventors; Valley Forge Scientific Corporation assignee. Bipolar RF generator. US Patent 5318563. June 7, 1994).

US005318563A

United States Patent [19]
Malis et al.

[11] **Patent Number: 5,318,563**
[45] **Date of Patent: Jun. 7, 1994**

[54] **BIPOLAR RF GENERATOR**

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[21] Appl. No.: **893,308**

[22] Filed: **Jun. 4, 1992**

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[52] **U.S. Cl.** **606/38**; 606/34; 606/37
[58] **Field of Search** .... 606/32–40; 128/419 R, 419 B

[56] **References Cited**

U.S. PATENT DOCUMENTS

4,590,934	5/1986	Malis et al.	128/303.14
4,716,897	1/1988	Noguchi et al.	606/37
4,727,874	3/1988	Bowers et al.	606/37
4,903,696	2/1990	Stasz et al.	606/37
4,934,377	6/1990	Bova et al.	606/34

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[57] **ABSTRACT**

An electrosurgical bipolar RF generator apparatus includes a bipolar electrode. An aperiodic sequence of uniform width bursts of a high frequency signal are electronically synthesized. Substantially identical decaying amplitude envelopes are impressed on the bursts of the high frequency signal. Each of the envelopes has a predetermined rate of change from a preselected initial amplitude. The impressed bursts of the high frequency signal are applied to the electrode. The electrical apparatus operates in a cut mode or a coagulation mode. The apparatus includes a power supply for providing a variable DC voltage, a short circuit detect circuit for detecting a short circuit at the bipolar electrode, and an open circuit detector for detecting an open circuit at the bipolar electrode.

17 Claims, 34 Drawing Sheets