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Adaptation of a standard low-field (0.3-T) system to the operating room: focus on pituitary adenomas

Borimir J. Darakchiev, MD[a], John M. Tew Jr, MD[a,b], Robert J. Bohinski, MD, PhD[a,b], Ronald E. Warnick, MD[a,b,*]

[a]Department of Neurosurgery, The Neuroscience Institute, University of Cincinnati College of Medicine, ML 0515, 231 Albert Sabin Way, Cincinnati, OH 45267–0515, USA

[b]Mayfield Clinic, ML 0515, 231 Albert Sabin Way, Cincinnati, OH 45267-0515, USA

Tumors of the pituitary gland were of interest to surgeons even before the establishment of neurosurgery as a separate specialty. Surgical treatment of the pituitary gland via the transsphenoidal approach evolved through many stages, from its ingenious introduction that was later abandoned and subsequently rediscovered decades later. In 1907, Schloffer pioneered its introduction, using the transsphenoidal approach to the gland via a superolateral nasoethmoidal route to remove a large intra- and suprasellar mass [1]. Two years later, Hirsch [2], who, like Schloffer, was from Austria, used the inferolateral endonasal transsphenoidal approach. In 1910, Harvey Cushing further refined the transsphenoidal approach by not only combining the best of the previous routes to the sphenoid sinus but by introducing the oronasal midline rhinoseptal transsphenoidal approach. This approach, with minor modifications, remains the standard surgical corridor used today by most neurosurgeons. In his remarkable Weir Mitchell lecture published in a 1914 issue of the *Journal of the American Medical Association* [3], Cushing described his experience using the transsphenoidal route for 247 pituitary adenoma cases.

Cushing noted two major drawbacks with this approach: first, the visualization of the field was suboptimal, and, second, the intraoperative assessment and removal of larger tumors with suprasellar extension were difficult. These difficulties were apparently major considerations in his decision to abandon the transsphenoidal approach and to adopt the transcranial approach. In the 1920s, Norman Dott of Edinburgh, a scholar of Cushing's in Boston, revived the use of the transsphenoidal route and introduced the approach in Europe [1]. In the early 1950s, Gerard Guiot of Paris studied this technique with Dott and further improved it with the introduction of intraoperative radiologic control [1].

With the innovative work and vision of Jules Hardy [1,4,5] in Montreal, interest in the transsphenoidal approach in North America was reborn. After training in transsphenoidal surgery with Guiot in France, Hardy made significant contributions to the neurosurgical field throughout his career, most importantly by the introduction of televised intraoperative fluoroscopy, operative microsurgical techniques, and the concept of pituitary microadenomas.

Neurosurgeons still face suboptimal intraoperative visualization of the pathoanatomic relations of the parasellar and suprasellar structures despite advances in magnification, illumination, microsurgical instrumentation, and technique during the last century. Limitations in visualization are especially pronounced in the surgical treatment of macroadenomas, which invade the cavernous sinuses or the suprasellar space. Implications of better visualization aimed at optimal tumor resection can be critical in the determination of the need for a second surgery or adjuvant therapy (eg, radiotherapy) and in patients in whom

* Corresponding author. c/o Editorial Office, Department of Neurosurgery, ML 0515, 231 Albert Sabin Way, Cincinnati, OH, 45267–0515.

E-mail address: www.mayfieldclinic.com (R.E. Warnick).

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a potentially resectable residual tumor is found on postoperative imaging. Several intraoperative imaging tools have been used to optimize the extent of resection and achieve the operative goals of transsphenoidal surgery since Hardy introduced fluoroscopic guidance as the first intraoperative imaging modality [4]. More sophisticated technologies have included frameless image guidance [6,7], ultrasonography [8–10], endoscopy [11], and intraoperative MRI (iMRI) [12–17].

The use of iMRI, particularly low-field units, during transsphenoidal pituitary adenoma surgery has been a subject of special interest in recent years. The University of Cincinnati Medical Center has developed substantial experience with its use in intracranial procedures, including transsphenoidal surgery. In 2001, we reported our initial results with the Hitachi AIRIS II 0.3-T vertical-field, open-magnet scanner (Hitachi Medical Systems America, Twinsburg, Ohio) for pituitary surgery [15]. In this article, we analyze the literature and review the current status of intraoperative low-field magnets used in the surgical treatment of pituitary adenomas. We describe the evolution of this technology in our practice and provide additional follow-up on our initial patients.

Intraoperative MRI in transsphenoidal neurosurgery: background

Literature review

In the late 1990s, Black et al [18] and Tronnier et al [19] reported the first use of iMRI scanners in neurosurgery. Their efforts rapidly triggered interest in this technology, predominantly for brain tumors, within the neurosurgical community as evidenced by an increasing number of publications, [20–26]. Several centers published their experience with iMRI during transsphenoidal procedures for pituitary macroadenomas [12–17]. The objectives of these studies were assessment of the safety and reliability of iMRI and the effectiveness of this imaging on completeness of tumor resection.

One of the first publications on the use of iMRI in transsphenoidal surgery was a preliminary report by Steinmeier et al [25] on a mixed group of patients. Eighteen patients underwent transsphenoidal procedures for two craniopharyngiomas, 15 nonsecreting macroadenomas, and one cystic macroprolactinoma. Based on the iMRI information, 3 of 5 patients underwent a second resection for residual tumor. Testing the reliability of iMRI by comparison with follow-up MRI scans (2–3 months), the authors established a high correlation between the two modes of imaging, thus concluding that iMRI was a reliable imaging diagnostic tool.

In a second more extensive study from the same institution, Fahlbusch et al [13] used the same open magnetic resonance imager (0.2-T Magnetom Open, Siemens AG, Erlangen, Germany) for 44 patients who had similar characteristics, that is, nonsecreting intra- and suprasellar pituitary macroadenomas. With suspicion of a residual tumor in 54% of patients based on the iMRI scans, repeat exploration was performed. However, only 34% of these patients had residual tumors that were found and resected. Although these false-positive iMRI interpretations occurred in 16% of patients, use of this technique led to an increased rate of complete tumor removal (from an initial 43% to 70% after additional resection). In the authors' experience, the major advantages of iMRI were the ability to maximize the extent of tumor removal, avoidance of artifact interference with the postoperative MRI scans, and early planning for any additional treatments needed. Two other smaller retrospective reports by Martin et al [12] and Pergolizzi et al [17] confirmed the benefits of iMRI. We later discuss our institutional experience with low-field iMRI in pituitary macroadenomas.

Current intraoperative MRI technologies for magnetic resonance operating rooms in neurosurgical applications

The iMRI evolved around three basic magnet configurations: the high-field strength, 1.5-T, cylindric, superconducting short-bore magnet [26–28]; the 0.5-T "double-doughnut" configuration [29,30]; and the biplanar, open, low-field, 0.12- to 0.3-T design [15,19,20,25,31–34]. These systems differ with respect to magnet field strength, distribution of the magnetic fringe field, image quality, speed of image acquisition, imaging capabilities (eg, functional MRI, magnetic resonance angiography, magnetic resonance spectroscopy), ability to use real-time MRI, operative position relative to the magnet isocenter, and cost-effectiveness.

In practical terms, the performance of surgery in a strong magnetic field is a complex task that relates to the strength and design of the MRI unit. Major limitations of such an environment prohibit the use of ferromagnetic surgical instruments, anesthesia equipment, and conventional operating microscopes. The strength of the magnetic fringe fields in the iMRI unit is a function of the distance from the magnet isocenter. Therefore, the field strength decays as the distance increases.

As described by Rubino et al [33], three magnetic fringe zones have been characterized that define the usability of ferromagnetic medical and surgical equipment. Zone I involves the area between the magnet isocenter and the 10-mT fringe field or 20-G line. Only MRI-compatible instruments, patient monitoring devices, and anesthesia equipment may be brought into this area. Zone II extends between the 10-mT and the 0.5-mT fringe fields (20-G to 5-G field lines). Zone II allows the use of most standard neurosurgical instruments by trained personnel but requires an MRI-compatible operating microscope. Zone III, which lies beyond the 0.5-mT fringe field (5-G line), is safe for the use of all standard instruments, operating microscopes, and frameless stereotaxy platforms.

The ability to perform surgery in any of these three zones essentially defined the design and organization of the contemporary iMRI operating rooms (ORs). Of the three approaches described, each offers its own advantages and disadvantages. The first iMRI scanner developed at Brigham and Women's Hospital in Boston by Peter McLaren. Black and Ferenc Jolesz [18] was based on the 0.5-T double-doughnut system that placed the surgical field within the MRI isocenter (zone I). Thus, iMRI scans could be obtained in real time during surgery without transporting the patient. This set up was costly, however, requiring the use of MRI-compatible surgical instrumentation.

In contrast to operations performed within the magnet, Tronnier et al [19] and Steinmeier et al [25] described the development of an alternative approach in Germany, known as the "twin operating theater." This concept consisted of two components. First, a conventional operating theater within the zone III field allowed surgery to be performed with the use of ferromagnetic instruments and an operating microscope. Second, a radiofrequency-shielded OR was designed for use with a low-field (0.2-T) MRI scanner. With the ORs located next to each other, patients can be transported from one room to another during surgery, thus permitting the goal of intraoperative imaging. Obvious disadvantages associated with this system were the inconvenience of transporting the patients, increased OR time, and risk of contamination.

A third approach described by the same authors [19,25] was initially used in small series for patients undergoing brain biopsies and transsphenoidal procedures. Rubino et al [33], Fahlbusch et al [13], Bohinski et al [15,31], and others further developed and used this approach. In a specially designed iMRI sterile OR, surgeons could operate within the weak magnetic fringe fields (beyond the 5-G line, zone III) and in close proximity to the magnet. Rotation of the table into the magnet volume allowed intraoperative images to be obtained quickly. This third concept combined the best of the first two approaches, namely, the ease of performing intraoperative imaging and the use of standard ferromagnetic equipment, and avoided patient transportation, time delays, and contamination to a sterile field.

Intraoperative MRI Center at the University of Cincinnati

Most experience with the use of iMRI in transsphenoidal surgery in the treatment of pituitary adenomas was acquired with low-field magnet scanners [12–17]. At our center, we developed an iMRI facility that includes a low-field magnet (Hitachi AIRIS II, 0.3-T, vertical-field, open-magnet imaging system).

Organization and intraoperative MRI setup

Our setup is based on the twin operating theater concept [19,25] in which one OR, which houses the Hitachi AIRIS II imaging magnet, links to a separate but adjacent conventional OR (Fig. 1). Our iMRI OR functions as a shared resource that provides services for diagnostic and intraoperative imaging. The addition of convenient access to the iMRI OR for outpatients undergoing diagnostic imaging distinguishes our facility from other previously described OR designs. This access permits the facility to be used not only for surgical procedures but for diagnostic imaging. With a location at a site close to but distinct from the main hospital OR suites, the iMRI center was also designed to incorporate scrub sinks and a self-sufficient material storage room.

The unit undergoes sterile cleansing between each diagnostic and intraoperative imaging session according to the requirements of the Joint Commission on accreditation of Health Care Organizations for OR environments. The facility was strategically built in the basement of the

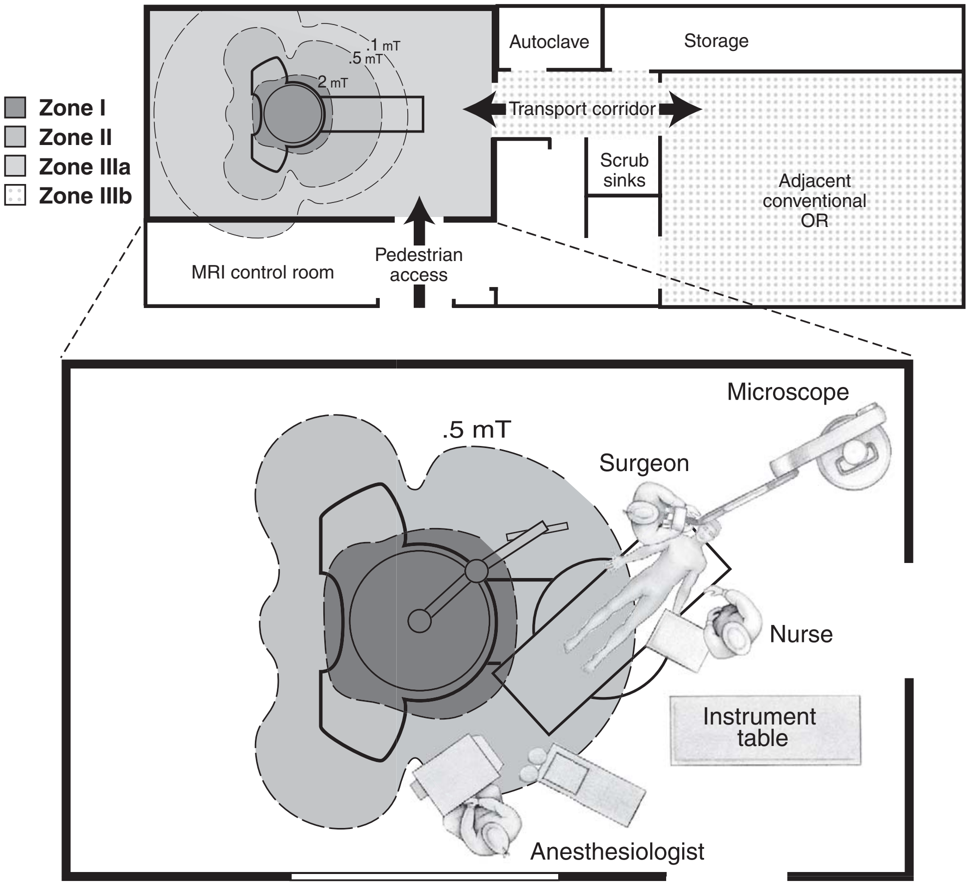

Fig. 1. Floor plan and layout of our twin operating theater design at the University of Cincinnati Medical Center. Transsphenoidal procedures are performed in the intraoperative MRI operating room. Patient positioning in magnetic fringe field zone III with the tabletop rotated to 120° (operative position). (*Courtesy of* the Mayfield Clinic, Cincinnati, OH.)

university hospital close to key departments (ie, radiology and emergency), the intensive care unit, and the main OR complex. This proximity facilitates patient transportation, pre- and postanesthesia care, and radiology interpretation of the scans.

Description of the low-field Hitachi magnet

The imaging device is a commercially available Hitachi AIRIS II, 0.3-T, vertical-field, open MRI unit that is used at many centers solely for diagnostic imaging purposes. The system has two horizontally oriented magnets that are separated by a distance of 17 in. The magnet has a vertical-field dual-column design that is common to the open MRI concept (Fig. 2). The magnet generates a horizontal spatial distribution of the static magnetic field (see Fig. 1B). The installation of this magnet in a fully functional OR environment at the University of Cincinnati Medical Center represents the first instillation of its kind in the United States.

Additional features of this scanner include a variable-position, radiofrequency-shielded, liquid crystal display (LCD) monitor; open-design radiofrequency receiver coils; a gantry illumination system; and custom-designed sterile gantry drapes. Two radiofrequency receiver coils were developed specifically for this setting. First, a nonsterile double-loop solenoid coil is sterile draped within the operative field. Second, a sterilizable single-loop solenoid coil can be placed directly in the operative field. Both coils must be placed vertically within the magnetic field for optimal image quality. The Hitachi AIRIS II table has

Fig. 2. Hitachi AIRIS II 0.3-T, vertical-field, open MRI system within its own operating room at the University of Cincinnati Medical Center during a transsphenoidal tumor resection. (*Courtesy of* the Mayfield Clinic, Cincinnati, OH.)

motorized controls that permit not only horizontal and vertical movement but rotation from 0° to 120° (0° corresponds to the patient's head located at the isocenter of the magnet, and 120° lies beyond the 5-G field line). The addition of this table to the system brought increased maneuverability during the patient positioning part of the process.

Practical aspects of transsphenoidal procedures in the intraoperative MRI environment: anesthesia, patient positioning, surgery, and imaging

Induction of anesthesia and intubation with a nonferromagnetic endotracheal tube is typically performed with the patient lying on a stretcher positioned next to the Hitachi AIRIS II tabletop. The gas exchange circuit is passed through the magnet and connected to an MRI-compatible anesthesia machine (Narcomed MRI; North American Drager, Telford, Pennsylvania), which is located opposite the scanner table. Vital signs are monitored with an MRI-compatible monitor (Omni-Trak 3150; In Vivo Research, Orlando, Florida). After intubation, the patient is transferred onto the tabletop, which is rotated to 120° (see Fig. 2) [35]. This rotation (as described previously) positions the patient's head in zone III, thus allowing the safe use of standard surgical instruments and the operating microscope. When positioning is completed, a double-loop solenoid coil is placed around the patient's head, centered at the level of the sella. Sterile draping of the operative field is performed in a standard manner.

A standard transsphenoidal sublabial-transseptal approach [36] is performed by an otolaryngologist, with exposure facilitated by an MRI-compatible titanium speculum. It can be left in place during imaging because it does not cause MRI artifacts in the sellar region. Confirmation of the surgical trajectory to the sella at the completion of the otolaryngologist's part of the exposure is occasionally obtained by imaging before opening the sellar floor. The MRI-compatible titanium speculum or a syringe filled with gadolinium contrast is used as guidance (Fig. 3). X-ray fluoroscopy was not used for localization in any procedure.

The microneurosurgical part of the procedure is also performed in a standard manner with the use of typical surgical instruments and a neurosurgical operating microscope (OPMI NC-4; Carl Zeiss, Thornwood, New York). All procedures are performed by four senior neurosurgeons whose combined experience exceeds 1500 transsphenoidal surgeries. A variable-position radiofrequency-shielded LCD monitor displays the microscope's field of view for the scrub nurse and observers in

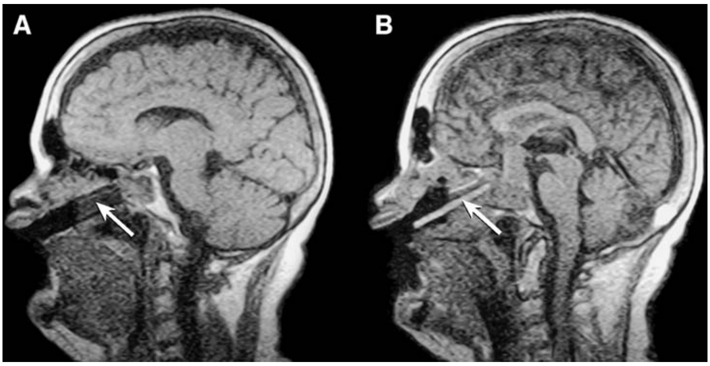

Fig. 3. Intraoperative MRI was occasionally used to verify the trajectory to the floor of the sella before its exposure. (*A*) Sagittal midline image with a cylinder-shaped signal void from the titanium speculum pointing at the sella (*arrow*). (*B*) An alternative localization technique using a tuberculin syringe filled with gadolinium (*arrow*). (*Courtesy of* the Mayfield Clinic, Cincinnati, OH.)

the room. During the surgical part of the procedure, the rotating tabletop remains angled at 120° (operative position). The procedure continues until the surgeon believes that all the accessible neoplasm has been removed. The table with the MRI-compatible speculum in place is swiveled back into the magnet to 0° for image acquisition. These steps, which can be completed within seconds, require neither additional manpower nor excessive OR time for repositioning. At the completion of iMRI, the patient is returned to operating position for closure or re-exploration. Second and, occasionally, third intraoperative imaging procedures can be performed to verify the completeness of tumor removal.

At the completion of the initial tumor resection, intraoperative imaging consisted of a T1-weighted, localizing, precontrast scout sequence in the sagittal plane (repetition time [TR] = 340 milliseconds, echo time [TE] = 20 milliseconds, 240-mm field of view [FOV], 4-mm slice thickness, 0.5-mm slice gap, acquisition time = 1 minutes 27 seconds), followed by precontrast sequences in the coronal plane (TR = 450 milliseconds, TE = 20 milliseconds, 220-mm FOV, 3-mm slice thickness, 0.5-mm slice gap, acquisition time = 5 minutes 46 seconds). If a satisfactory resection was established, postcontrast coronal sequences were performed for confirmation purposes. In cases in which additional resection was needed, the contrast imaging was delayed until the repeat precontrast sequences demonstrated that the goal of the surgery was achieved. Our practice is to obtain postcontrast images after the completion of surgical removal so as to avoid artifacts from a contrast leak in the surgical field, which can confuse interpretation of the images. The contrast agent used was Omniscan (gadodiamide, 287 mg/mL; Nycomed, Princeton, New Jersey). A standard single dose (0.2 mL/kg [0.1 mmol/kg]) of Omniscan was administered in all patients. The time for the intraoperative imaging session, including review of the images and patient positioning adjustments, averaged 30 minutes. Typically, the surgical team remained scrubbed during this first imaging process. The surgeon was then able to review the images inside the iMRI OR with the in-suite MRI-compatible monitor. A final intraoperative imaging procedure was not performed routinely after closure to conserve operative time and resources. We obtain postoperative imaging within 1 to 3 months after surgery, particularly in patients who require additional treatment (eg, stereotactic radiosurgery).

Results

Between 1998 and 2004 at the University of Cincinnati Medical Center, 115 patients with pituitary macroadenomas underwent iMRI-assisted transsphenoidal surgery. The first 30 of these patients were included in a prospective study protocol previously reported [15]. We summarize our experience with this group of patients and discuss their additional follow-up.

Patient characteristics

Patients included 18 men and 12 women who ranged in age from 24 to 74 years (mean = 51 years). Twenty-six patients had newly diagnosed tumors, and 4 patients presented with recurrent disease after previous surgical resection. The clinical presentation included visual field deficits in 16 patients, endocrine disturbances (acromegaly in 6 patients, hypopituitarism in 3 patients, and Cushing's disease in 2 patients), and headaches in 3 patients. All hormone-secreting tumors were confirmed with immunostaining. Tumor size was consistent with macroadenomas in all cases and averaged 27 mm in maximal diameter. All patients had suprasellar extension of the tumor, including grade 1 (5 patients), grade 2 (16 patients), and grade 3 (9 patients) according to the scale of Knosp et al [37]. Patient information was collected prospectively and analyzed in a standardized computer database.

Surgical results and clinical follow-up

Of the first 30 iMRI surgical procedures, 29 were completed uneventfully; one patient had an unsuspected intraventricular hemorrhage that was detected by intraoperative scans and treated successfully with an emergent craniotomy. Second and third re-explorations were performed for resection of residual tumors demonstrated on iMRI in 19 patients and 3 patients, respectively. The goals of surgery varied based on the extent of tumor growth into the cavernous sinuses and suprasellar space. Although we strive for optimal tumor removal, the planned surgical goal in some cases was clearly subtotal resection (STR). For example, for 13 patients with macroadenomas of grade 2 or greater, the surgical goal was decompression of the optic chiasm, followed by radiation treatment to the residual tumor that invaded the cavernous sinuses. The criteria for optimal STR based on the MRI scans included the absence of residual resectable tumor 3 mm or greater from the optic apparatus and the presence of a noninvasive plane along the cavernous sinuses. In the remaining 17 patients, who had no imaging evidence of invasive disease, gross total resection (GTR) was planned. iMRI successfully demonstrated residual resectable tumor in 56% of patients after GTR and in 77% of patients after STR. GTR was typically accomplished after a second exploration when imaging indicated the presence of residual tumor (Fig. 4). The intraoperative images were of diagnostic quality and comparable to postoperative 1.5-T localization MRI scans performed in patients who also underwent radiosurgical treatment. Compared with the postoperative images, the presence of residual tumor was more effectively detected on the iMRI scans because of the absence of signal interference from the fat graft and sellar reconstruction.

At the clinical follow-up, 15 of 16 patients with visual field deficits had improvement that was documented by formal visual testing. One patient developed a delayed postoperative hematoma that caused acute visual decline and necessitated emergent reoperation. Endocrine function improved in most of the patients. The 3 patients with hypopituitarism continued on long-term hormonal replacement therapy. All 6 patients with acromegaly showed gradual postoperative normalization of growth hormone levels and insulin-like growth factor 1. As part of a planned STR, 3 of the 6 patients underwent postoperative adjuvant stereotactic radiosurgical treatment for nonresectable tumors that invaded the cavernous sinuses; their hormonal levels also normalized after treatment with octreotide (sandostatin). Although the signs of hypercortisolism in the 2 patients with Cushing's disease resolved after surgery, these patients developed panhypopituitarism that required medical management as a result of the total hypophysectomies performed. All patients with less specific symptoms (eg, headache) reported symptomatic improvement. No complications were attributed to interaction between the magnet and anesthesia equipment or surgical instrumentation.

Drawbacks of intraoperative MRI

In our experience, two factors that can potentially interfere with intraoperative imaging interpretation in transsphenoidal procedures are blood products and contrast media. Blood products, which accumulated in the surgical field, including the sphenoid sinus and sella, need to be distinguished from residual tumor. Clotted blood had isointense signal on pre- and postcontrast sequences. Tumor and normal gland enhance after contrast administration, which is typically more pronounced in the gland. Leaking of contrast mixed with blood products in the surgical cavity can be another confusing element that makes differentiation from residual tumor more difficult. Therefore, we abandoned our initial approach of contrast administration immediately after the first surgical attempt. We now reserve contrast imaging for the final preclosure stage of the procedure, only after the precontrast sequences demonstrate that the planned extent of resection has been achieved. With this practice, we have successfully avoided the issue of confusing imaging artifacts

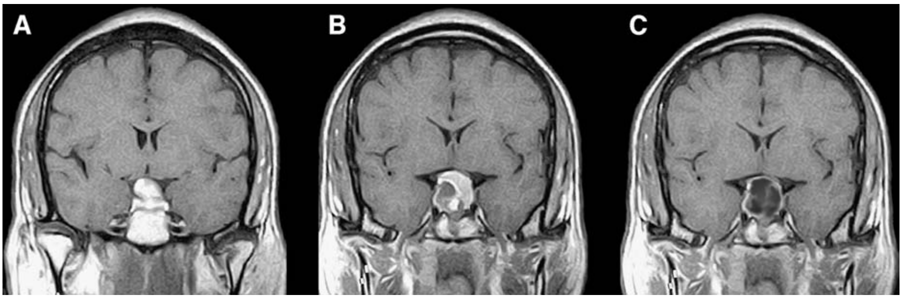

Fig. 4. Intraoperative MRI (iMRI) coronal, T1-weighted, contrast-enhanced serial views. (*A*) iMRI scan before a planned gross total resection (GTR) in a patient with a pituitary macroadenoma with suprasellar extension. (*B*) First iMRI scan after the initial resection demonstrated residual tumor. (*C*) During a repeat surgical exploration, GTR was confirmed with this second intraoperative imaging. (*Courtesy of* the Mayfield Clinic, Cincinnati, OH.)

from contrast in the surgical field and thus can accomplish the surgical goals.

Discussion

At our iMRI center at the University of Cincinnati Medical Center (1998–2004), we have successfully operated on more than 100 patients with pituitary macroadenomas via the transsphenoidal approach. In our experience, the Hitachi AIRIS II 0.3-T shared-resource MRI scanner was especially valuable in providing intraoperative images of diagnostic quality and detecting residual tumor amenable to further resection. With use of the iMRI scanner, we eventually accomplished our planned surgical goals in all patients; without this scanner, we would have accomplished these goals in only 34% of the patients. As described in the previous section, iMRI demonstrated residual resectable tumor in 56% of patients for whom GTR was the goal of surgery and in 77% of patients for whom STR was the goal. This difference indicates that the likelihood of incomplete resection is greater in larger invading tumors, for which iMRI becomes especially valuable. Our experience generally showed a higher incidence of residual disease found with iMRI when compared with other reports [13]. Possible factors that may have contributed to this incidence included reliance on the immediate availability of a ‘‘second iMRI look,’’ a learning curve with this new technology, and inclusion of patients with extremely large difficult-to-resect tumors referred to our center.

Some characteristics in our setup are unique and allow for significant flexibility in terms of practicality and convenience. Our facility is based on the twin operating theater concept and offers a significant advantage in ease of use that is facilitated by the rotating tabletop. The surgeon can operate within magnetic-fringe field zone III with conventional surgical instruments and a microscope, thus saving significant resources and time. The use of the second ‘‘conventional’’ OR is reserved exclusively for cranial cases that require lateral or ‘‘park-bench’’ patient positioning, which the MRI tabletop cannot accommodate. The location of our unit is close to strategic facilities, such as the main OR complex; intensive care unit; and radiology, anesthesia, and emergency departments. This location facilitates patient care and transportation as well as communication among specialists during image interpretation.

One of the most important features of our iMR-OR design is the shared resource capability that allows for out- or inpatient diagnostic use when the unit is not in use as an intraoperative imager. This aspect of the unit makes it cost-effective when compared with other available designs. Our approximate costs included $1 million for the Hitachi AIRIS MRI scanner, $1.5 million for the twin operating theater construction, and $250,000 for annual operating expenses. In our cost analysis, we determined that our iMRI facility covers its expenses by performing 1000 diagnostic scans per year (20 per week). During a 2-year period (2002–2003), we performed almost 1200 diagnostic scans annually and thus surpassed our ‘‘break even’’ point.

Although use of iMRI increases operative time, this drawback is common in other similar systems. Each intraoperative imaging session in our patients added an average of 30 minutes to the OR time. However, this additional OR time was justified by a more precise tumor resection, which could potentially prevent or delay a second procedure or adjuvant treatment for patients.

In our experience, iMRI provides the surgeon with the unique capability to maximally accomplish the planned goal of surgery. Such accuracy is especially important in nonsecreting pituitary macroadenomas in which resection is the only means to minimize the chance of recurrence. iMRI allows the surgeon to assess the extent of tumor resection immediately and to detect any surgical complications. The potential benefits of iMRI are a decrease in the rates of a second surgical resection because of undetected residual tumor (at least during the immediate and intermediate postoperative periods) and a greater opportunity for detection of smaller targets when additional treatment (eg, stereotactic radiosurgery) is needed. A clear measure of the effectiveness of iMRI on tumor recurrence and survival rates has not yet been demonstrated because of the slow growth rate of these tumors. Such a potentially beneficial relation needs to be demonstrated in a prospective, controlled, long-term follow-up trial.

Summary

iMRI is a reliable and safe tool to monitor the extent of resection and to avoid complications in the transsphenoidal surgical approach for pituitary tumors. The best indication for its application in transsphenoidal surgery is for patients with pituitary macroadenomas with suprasellar extension. The low-field 0.3-T magnet has a diagnostic imaging quality that provides surgeons with good intraoperative detail of the anatomic relations in the sellar region. In our experience, iMRI provided a distinct benefit in planned STR for invasive macroadenomas that compress the optic chiasm and in planned GTR for noninvasive tumors. The iMRI design adopted at our center includes important features, such as the use of ferromagnetic surgical instruments, elimination of patient transportation, and capability as a shared resource, that allow multipurpose diagnostic use and increased cost-effectiveness.

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