

# Physician

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*"The essence of neuro-surgery is that we help others through skills that see and touch the nervous system. We work in complicated, small, even tiny places where taking the wrong road may cause great damage. The study of this complicated art is to take what is a delicate, awesome, and fateful experience for our patients and make it accurate, gentle and safe."* Albert L. Rhoton, Jr., MD, former president, American Association of Neurological Surgeons

*"No technique in neuro-surgery would be too refined, particularly in reference to the ability to localize lesions."* Lars Leksell, MD, pioneer developer of the Gamma Knife

The two greatest advancements in the practice of neuro-surgery have been the introduction of the operating microscope and the development of magnetic resonance imaging (MRI).

The operating microscope provides stereoscopic vision with intense illumination, allowing for the microscopic delineation and preservation of neural and vascular structures. The increased visual accuracy, smaller cortical incisions, decreased need for retraction, and pinpoint hemostasis and dissection made possible through use of the operating microscope has allowed surgeons to reach deep areas of the brain with decreased operative morbidity and mortality.

MRI has allowed for improved localization and diagnosis of intracranial lesions. Its improved tissue contrast properties and variety of imaging

modalities have allowed specialists to diagnose low-grade tumors that were invisible on previous CT studies. The versatility of MRI has been demonstrated in its ability to image not only brain tissue and associated pathology but also the arterial supply (MR angiography), venous drainage (MR venography), cerebral spinal fluid dynamics (MR flow study), metabolic properties (MR spectroscopy), localization of eloquent cortex (MR functional study), and neural connectivity (MR tractography).

A combination of the two techniques to improve localization and minimize surgical trauma is implemented in currently available image guidance systems. The patient is pre-operatively scanned with a series of fiducial markers placed on the skin of the skull. After the patient is positioned for surgery, the fiducial markers are used to register the brain and associated structures in three-dimensional space using the image guidance system. The surgical approach is then planned using this information, and a variety of instruments can be registered in the system to allow for localization.

The main weakness of this system is demonstrated at the

## Taking aim

### *Intra-operative MRI in neurosurgery*

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time of surgery. Opening of the skull and dura and the resulting drainage of cerebral spinal fluid can cause the brain to shift its position considerably (up to 1 cm), making the guidance data of limited use. This shift and tissue distortion is only magnified with the resection of tumor or manipulation of the brain with retractors. A variety of methods have been used to circumvent this problem. Intra-operatively obtained ultrasound and CT data have been used. However, both techniques lack the necessary tissue contrast properties and inherent flexibility of the pre-operative MRI scan.

Ideally, a system would allow the surgeon to plan the surgical approach using the most accurate functional and anatomic data available, and then be able to update this data intra-operatively to allow for the inevitable shift caused by surgery. The use of intra-operative MRI (IoMRI) allows for this possibility. Although the data is not updated in real time, it is possible to scan the patient at any time during surgery. A variety of paradigms have been implemented utilizing both low- and high-field scanners. Below we describe the system at Abbott Northwestern Hospital

in Minneapolis and our experience utilizing this technology.

#### **Description of IoMRI**

The IoMRI room at Abbott Northwestern Hospital is an integral part of the operative room suites. It is uniquely dedicated to surgical procedures with designated nursing, surgical technologist, and anesthesia staff.

The IoMRI consists of a ceiling-mounted 1.5-Tesla Espree Scanner (Siemens Wide-Bore 70 cm) adapted by Imris (Fig. 1). The scanner is kept outside the OR in a shielded closet for most of the procedure and is brought into the OR only when it is needed for imaging. This has several advantages for the patient and OR staff. First, since the OR is outside the 5 gauss line for most of the procedure, the OR can be normally sized and equipped. Second, the scanner is not an obstacle to be worked around and does not require patient movement, making it less likely to disrupt an important line or monitoring device. Third, an operating room table can be used for patient positioning, allowing for increased versatility and safety.

For patients undergoing planned intracranial procedures, a high-resolution, thin-slice MRI of the brain is obtained 24 to 48 hours in advance. Advanced pre-operative scanning is particularly important for tumors that enhance with the administration of gadolinium contrast. Immediate pre-operative contrast administration can lead to a progressive "leak" of contrast



FIGURE 1. View of the ceiling-mounted 1.5-Tesla Espree Scanner (Siemens Wide-Bore 70 cm) adapted by Imris docked to the operating room table in the scanning configuration. Non-MRI-compatible equipment, such as the operating microscope and image guidance display monitors shown in the upper right-hand side of the picture, are moved beyond the 5 gauss line demarcated by the white area on the floor.

into the brain parenchyma, which degrades intra-operative scans. More extensive studies such as MR angiography, MR venography, MR spectroscopy, MR functional scanning, and MR tractography can be performed at this time as well and are mapped onto the high-resolution scan to allow for appropriate surgical planning.

The morning of surgery, the patient will undergo either a pre-operative high-resolution MRI without contrast or a high-resolution CT without contrast that is used to register the patient's intracranial space in three dimensions using the intra-operative image guidance system. Any pre-operative scans and the associated plans can then be "merged" onto the newly acquired registration scan using the provided software with a very high degree of accuracy.

After induction of anesthesia, surgical positioning, and preparation, the procedure is undertaken with standard neurosurgical approaches using standard instrumentation. An intra-operative scan may be obtained at any time during the procedure. To prepare for an intra-operative scan, hemostasis is obtained, all metallic surgical instrumentation is removed from the surgical field, the wound is temporarily closed, and all non-MRI-compatible instrumentation and equipment is moved outside the 5 gauss line that will be created when the scanner is brought into the OR. The patient is then draped to protect the surgical field and

the scanner is positioned. Scans then are obtained using defined protocols and are reviewed with the operating surgeon and neuro-radiologist to determine the extent of resection. If no more resection is required, the scanner is removed and the surgical wound is closed permanently. If further surgical resection is required, the scanner is removed and the surgery proceeds as before. In our experience, one-third of patients will undergo more than one intra-operative MRI before completion of the surgery.

The two areas of greatest potential for IoMRI utilization are the resection of pituitary adenomas and of low-grade gliomas near eloquent cortex (Fig. 2). The challenge and greatest risk to the patient in pituitary surgery is removal of tumor near or within the region of the cavernous sinus. The dissection in this area cannot be directly visualized and too aggressive an approach puts the patient at risk for a vascular injury. IoMRI enables the surgeon to determine whether there is any residual tumor within this region, allowing for alteration of dissection technique. For low-grade gliomas near eloquent cortex, the use of functional MRI and MRI tractography allows for clear delineation of structures and pathways that need to be protected during resection to prevent a neurologic deficit. MRI tractography can be repeated intra-

operatively to compensate for brain shift and tumor resection. Future developments may allow for updated functional information as well.

### Results of interventions

Since the introduction of IoMRI at Abbott Northwestern Hospital 15 months ago, 158 neurosurgical procedures, both adult and pediatric cases, have been completed. There were 28 pediatric patients, ranging in age from 3 to 21, and 120 adult cases. The vast majority of the patients harbored brain tumors, including: 88 primary gliomas, 25 meningiomas, 15 pituitary adenomas, 13 unclassified, six metastatic tumors, eight vascular malformations, and three congenital lesions.

IoMRI-related complications included both intra-operative and post-operative complications. Intra-operative complications included an epidural hematoma related to the pin site. Post-operative complications were surgical wound site infections (skin) not requiring additional surgery and were probably related to issues of procedure length and multiple scans.

The integration of neuro-navigation and the addition of functional MRI and MR tractography imaging capabilities to the IoMRI have further enhanced the likelihood of safer, more accurate, and more complete tumor and lesion resection while preserving neu-

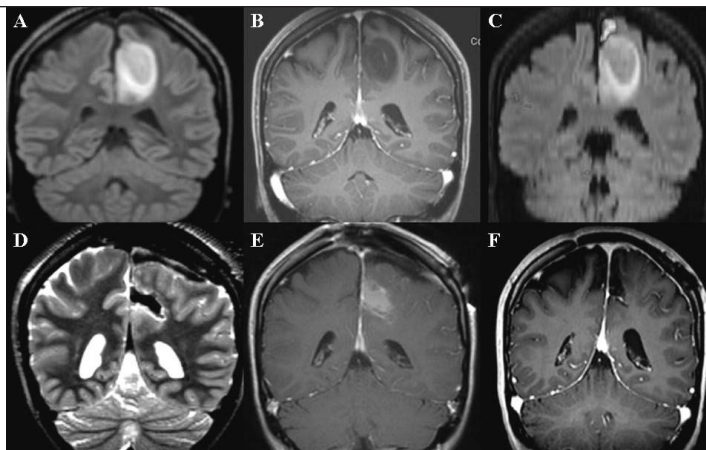


FIGURE 2. A 27-year-old, right-handed female presenting with simple partial seizures consisting of intermittent right leg tingling and dyscoordination. MRI of the brain demonstrated a lesion in the left posterior frontal lobe that was hyper-intense in T2-weighted imaging (A) and hypo-intense on T1-weighted imaging without significant gadolinium enhancement (B). Functional MRI using a toe-taping paradigm (C) demonstrated that the lesion was under the motor cortex for the right leg. The patient underwent an IoMRI-guided craniotomy for surgical resection. IoMRI scans, T2-weighted (D), and T1-weighted with contrast (E) demonstrated radiographically complete resection. Post-operatively, the patient experienced a mild right foot drop that resolved within three months. Surgical pathology was consistent with a WHO Grade II glioma. Two-year post-operative scan (F) demonstrated no evidence of recurrent disease.

rologic function. The inclusion of intra-operative MRI undoubtedly prolongs the surgical time and increases the surgical costs. However, initial analysis pointing to the decrease in second-look surgeries and immediate recognition of operative complications may compensate for the time and cost issues.

The preliminary results point to:

- Greater incidence of near-total or total tumor resection due to enhanced accuracy in lesion localization.
- Preservation of neurologic function near eloquent cortex and deep nuclei.
- Decrease in the number of "second look" surgeries.
- Decrease in the number of imaging studies during the postoperative period.
- Greater opportunity for immediate recognition of intra-operative complications.

### Improved quality of life

In our experience, the application of IoMRI to brain surgery has enhanced the likelihood for near-total or total lesion resection while limiting potential harm to eloquent cortex or deep nuclei. The combination of IoMRI with frameless neuro-navigation has allowed for more accurate definition of the surgical approach by compensating for "brain shift." This is particularly enhanced with the addition of functional MRI and MR tractography, allowing for preservation of neurologic function. It is hoped that in the long term, this will lead to increased quality of life for our patients. Certainly in the short term, the immediate recognition of intra-operative complications and decrease in the number of second-look surgeries serves to decrease the morbidities associated with neurosurgical procedures. ▣

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