



front line

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Intraoperative Magnetic Resonance Imaging

Magnetic resonance imaging (MRI) has been widely used as a powerful diagnostic tool for more than twenty years. The high-contrast sensitivity, multiplanar display, absence of bone artifact and specific biochemical information offered by MRI have enabled increased detection and characterization of pathology across a broad range of diagnoses.

Technology has now been developed to bring these advantages of MRI into the operating room, offering real-time guidance during surgery. Intraoperative MRI (iMRI) joins frameless stereotactic systems and modern operating microscopes to further improve surgical visualization and navigation.

The main application of iMRI to date has been to guide brain surgery, where it is valuable for several reasons:

- Because of high tissue contrast, MRI can define the borders of some tumors and the location of some normal brain structures better than the eye of the surgeon or other current imaging techniques.

- MRI provides a full field of view for the surgeon, which is helpful when direct visualization is limited by the operative exposure (e.g., transphenoidal pituitary surgery).
- MRI performed intraoperatively demonstrates the movement or shift of brain tissue that has occurred during surgery, providing a real-time update to the spatial information from preoperative scans.
- MRI at the end of an operation can confirm that the surgical objectives have been accomplished, and that no complications have developed, before the craniotomy is closed.

Centers that are experienced with iMRI have reported that intraoperative scans lead to adjustments of surgery in 25 percent to 35 percent of cases. High-resolution iMRI is particularly valuable for:

- resection of tumors located close to key functional areas
- removal of pituitary tumors and other masses along the skull base
- procedures for epilepsy
- functional neurosurgery targeting precise locations – e.g., placement of electrodes for deep brain stimulation to treat movement disorders.

Intraoperative MRI scanners are available with either weak or strong magnetic fields. “Low-field” iMRI scanners offer the advantages of relatively lower cost and less concern about safety hazards, but the images they provide are somewhat limited in resolution and field-of-view. “High-field” iMRI scanners are more expensive and require greater vigilance for safe operation, but they provide superior image quality. Most major neurosurgical centers have chosen to implement iMRI with high-field scanners, typically using 1.5 Tesla magnets, comparable in strength and resolution to diagnostic scanners.

A variety of approaches have been developed to provide high-field MRI guidance during surgery:

- A diagnostic MRI room can be designed to accommodate some surgical procedures adjacent to the scanner by adjusting floor heights, air flow, etc.
- A MRI scanner can be installed in a room adjacent or connected to an operating suite. Patients are transferred from the OR to the scanner and back again on a transport cart.

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Dear Colleagues,



I am pleased to report that Abbott Northwestern Hospital has again been ranked among the top 25 hospitals in the United States for neurology and neurosurgery by *U.S. News and World Report*. This rating is based on reputation, capabilities and outcomes. The ranking is a testament to the outstanding care provided by the hospital's nurses and physicians, and to the investments that have been made over the past two decades to develop specialized neuroscience resources on our campus. For a recent example, see the article on intraoperative MRI by Douglas Yock, MD in this issue.

Best regards,

Mahmoud Nagib, MD

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- A MRI scanner can be permanently installed within an operating room. The patient is moved between the operating position and the scanning position, e.g. by rotating the patient table around a pedestal.
- A MRI scanner can be suspended from rails in the ceiling of the OR so that it can be moved into and out of the operating room as needed.

There are several advantages to this last approach – mobile, high-field iMRI:

- The iMRI room is a normally sized and equipped neurosurgical OR. For example, the operating table is much more versatile for patient positioning than the usual table of a diagnostic MR scanner.
- The scanner comes to the patient. The patient does not have to be moved or rotated into the scanner, which is time-consuming and can disturb the operative field and/or attached lines and monitors.
- The scanner is outside of the OR for most of the operation, coming into the room only when it is needed for imaging. The unit is not always present as an obstacle to work around or as a strong magnetic field with the risk of attracting ferromagnetic objects.

Douglas H. Yock, Jr., MD, graduated from Harvard Medical School, Cambridge, Mass., and completed an internship and residency in diagnostic radiology at Stanford University Medical Center, Stanford, Calif. This was followed by a fellowship in neuroradiology at Stanford and the University of California in San Francisco. He is a senior member of the American Society of Neuroradiology and a fellow of the American College of Radiology.

Yock has practiced neuroradiology in Minneapolis for 30 years. He currently serves as director of Abbott Northwestern's MRI Center and he chairs the hospital's advisory board of neuroscience physicians. ■



Abbott Northwestern Hospital completed installation of a 1.5 Tesla mobile intraoperative MRI scanner in June 2007. The scanner is the fourth unit of this type in the United States and the fifth worldwide. Several dozen brain operations have been performed in the new suite, with very encouraging results. Image quality has been excellent. In several cases, intraoperative visualization has led to more complete and more accurate resection of a tumor than would have been accomplished without this guidance. The result is reduced risk of tumor recurrence, reduced risk of operative complications and reduced need for repeat craniotomies.

In summary, iMRI is a valuable addition to the technology guiding surgeons in the operating room and enabling improvements in outcomes for patients. ■

Fifteen neurosurgeons from four different groups use the resources of the neurosurgical operating rooms at Abbott Northwestern Hospital. More neurosurgical procedures are performed at Abbott Northwestern than at any other hospital in the Twin Cities – about 2,000 per year. Based on capabilities and outcomes, Abbott Northwestern Hospital is consistently ranked among the top 25 hospitals in the United States for neurology and neurosurgery by U.S. News & World Report.

Heading Off Migraines with New Insights



Sara Langer, MD, graduated from the University of Minnesota Medical School, Minneapolis, and completed her neurology residency and neuromuscular fellowship at the University of Michigan Medical School, Ann Arbor, Mich. She is a member of the Noran Clinic, working as hospital neurologist at Abbott Northwestern Hospital. ■

We have arrived at a time when treating migraines has become easier and more rewarding for both physicians and patients. Recent discoveries in migraine pathophysiology have revealed a complex array of mechanisms. These insights have made way for a wide variety of effective interventions. For example, it has been noted anecdotally that eating protein or certain high-protein diets seems to reduce migraines. Recent studies have demonstrated that diets of balanced amino acids rich in L-tryptophan reduce migraine symptoms, presumably by increasing brain synthesis of serotonin. New knowledge of these neural pathways helps us make sense of the many different

clinical manifestations of migraine that we observe.

Conceptualization of migraine genesis has shifted in the past 20 years, from the theory that migraine is principally a derangement of blood vessel tone and blood flow to the theory that migraine is a disorder of neurotransmitters and neural dysfunction. Many important vascular changes occur, but they are secondary to neural signaling. This hypothesis holds that an individual with migraines has a genetic or acquired low cerebral threshold to migraines. When precipitating factors individually or collectively exceed the threshold, an attack occurs.

One of the initial phases of migraine associated with aura is cortical spreading depression. In this model, some endogenous or external sensory stimulus causes a wave of depolarization that moves across the cortex at a rate of 3-5 millimeters per minute. This is followed by a wave of nerve cell depression. The location and rate of cortical spreading depression can explain the aura symptoms experienced by the patient. At the same time, the cortical spreading depression results in the release of potassium, protons, neurotransmitters and metabolites. These substances can activate perivascular nerve endings of the trigeminal nerve, which has direct and indirect connections to the meningeal blood vessels, causing pain. Other neurons in the trigeminal nerve project to the brainstem and higher brain centers, causing a host of other symptoms.

Common triggers for migraine include sleep excess or deprivation, emotional or physical stress (for example, overexertion or dehydration), bright or flickering lights, odors or perfumes, weather changes and sexual activity. Changing hormonal status at the time

Dorsal Column Stimulation

Dorsal column stimulation (DCS) is a reversible neuromodulation modality used to treat certain chronic pain conditions. Also known as spinal cord stimulation (SCS), the first report of DCS in humans was published in 1967¹, and it has been used successfully in select patients for the past 30 years.

Indications

There are several indications for DCS. The following is a list adapted from a chapter in *Surgical Management of Pain*². The indications are listed in order of decreasing efficacy:

1. Failed back syndrome. Patients with radiculopathic pain predominating over axial and mechanical pain are the best candidates^{3,4}
2. Peripheral nerve injury, neuralgia, or causalgia^{5,6}
3. Ischemic pain due to occlusive or vasospastic arterial disease (e.g. angina pectoris)⁷
4. Phantom limb or stump pain⁸

Patient Selection

Patient selection is extremely important. Medicare and most third-party payers

require the following inclusion criteria as obtained from the Medicare Coverage Database⁹:

1. The implantation of the stimulator is used only as a late resort (if not a last resort) for patients with chronic intractable pain;
2. With respect to item 1, other treatment modalities (pharmacological, surgical, physical, or psychological therapies) have been tried and did not prove satisfactory, or are judged to be unsuitable or contraindicated for the given patient;
3. Patients have undergone careful screening, evaluation and diagnosis by a multidisciplinary team prior to implantation. (Such screening must include psychological, as well as physical evaluation);

Jon McIver, MD, earned his medical degree from the Loma Linda University School of Medicine, Loma Linda, Calif., in 1999 and was president of his graduating class. He completed his neurosurgical residency in 2006 at the Mayo Clinic, Rochester, Minn. While in residency he was a clinical research training program scholar and received the Karis and Individual Excellence Awards. He completed a neurosurgical fellowship in stereotactic and functional neurosurgery at the University of Toronto in 2007.

McIver's major clinical interests are deep brain stimulation for movement disorders and pain, dorsal column stimulation for failed back syndrome, minimally invasive treatment of spinal disorders, and radio-surgery for tumors, pain and tremors. ■



4. All the facilities, equipment, and professional and support personnel required for the proper diagnosis, treatment training, and followup of the patient (including that required to satisfy item 3) must be available; and
5. Demonstration of pain relief with a temporarily implanted electrode precedes permanent implantation.

The following is a description of a patient that counseled in favor of having DCS:

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of ovulation, menstruation, pregnancy and menopause substantially affect the frequency and severity of migraines. Oral contraceptives and hormonal chemotherapy, such as leuprolide (Lupron), may increase or decrease migraines. The list of potential food triggers is very long and differs from person to person. Most people are unaware of their food sensitivities. Dietary triggers are dose related and cumulative, so that eating small portions of a food trigger over a period of time may precipitate a migraine, often several hours afterward. Restricting amounts of some of the most common offenders, such as alcohol, chocolate, nuts and ripened cheese, helps many individuals. Caffeine is particularly troublesome. Although caffeine may abort a single headache, excessive use causes rebound headaches. For people with frequent migraines, it is useful to eliminate caffeine altogether.

Acute migraines may be effectively aborted by nonsteroidal anti-inflammatory agents, mild sedatives such as bupropion, or low potency sympathomimetic agents such as Midrin. Sleep aborts migraines in many people. However, as migraines become more frequent or refractory to the above medications, acute migraine management often combines an anti-inflammatory agent, antiemetic medication and specific migraine drug such as a triptan. In situations in which oral medications fail, some medications can be self-administered nasally or subcutaneously. Finally, intravenous administration of ketorolac or a corticosteroid, in conjunction with metoclopramide or ondansetron AND valproate sodium works extremely well for severe migraines. One of the advantages of valproate sodium is that it can be used in individuals who cannot have medications that potentially cause vasoconstriction, tachycardia or hypertension. Narcotic analgesics are not

recommended in patients unless they cannot take anything else, for example pregnant patients in their first trimester.

Preventive therapy should be initiated when a patient has recurring migraines that, in the patient's opinion, significantly interfere with his or her routines despite acute treatment. The US Headache Consortium has a Web site outlining a number of other considerations which may be used to determine when to initiate prophylactic treatment. One reason to institute preventive treatment is the notion of sensitization of the nervous system, whereby frequent volleys through the migraine pathways prime the brain for more frequent and severe migraines. Choosing a prophylactic migraine medication involves identifying comorbidities that could predispose to migraines or could be treated with the same medication. An example of a comorbid factor is depression. Using an SSRI can be effective for both migraine prophylaxis and depression. Anticonvulsants are considered first-line therapy for migraine prophylaxis. Only valproic acid and topiramate are FDA approved for this purpose, but other anticonvulsants such as lamotrigine and pregabalin can be helpful. Nonselective beta-blockers and some centrally acting muscle relaxers are also effective in some patients. Calcium channel blockers are now used primarily for refractory cluster headaches because of the risk of cardiac arrhythmia. Each of these medications has potentially intolerable side effects, ranging from significant weight gain with impaired glucose tolerance to cognitive deficits. The physician must consider the whole patient in selecting a preventive therapy to minimize the impact of side effects. ■



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Dorsal Column Stimulation, *continued from page 3*

A 71 year old female presented with a left L5 radiculopathy in 2001 and was diagnosed with a left L4-5 disc herniation. She underwent left L4-5 microdiscectomy but her pain did not improve. In 2006, she was diagnosed with a recurrent L4-5 disc extrusion. She then underwent revision microdiscectomy, but reported that the pain was actually worse after the second surgery. The pain radiates from the left buttock, into the posterolateral thigh, and past the knee into the anterolateral leg. She describes the pain as constant, dull, burning and aching. MRI of the lumbar spine revealed enhancing tissue around the left L5 root, no recurrent disc, and no evidence for root compression.

Procedure

A screening protocol is recommended. Mapping of the epidural space is used to identify the optimal electrode position. This is followed by a therapeutic trial in which pain relief is assessed, primarily. A minimum pain reduction of 50 percent is the most common definition of success. This screening process can be performed with either percutaneous leads or an insu-

lated plate (which requires a laminotomy). If the trial stimulation is successful, the permanent electrodes are placed along with an implantable pulse generator. If trial stimulation is not successful, the electrodes are removed.

Mechanism of Action

The neurophysiological mechanisms of action are most likely multiple and are summarized by the following:

1. According to the gate-control theory⁹, an inhibitory control of dorsal horn nociceptive neurons is facilitated by activation of large fiber pathways in the dorsal columns. Collaterals from these pathways project antidromically to the same spinal segment as the nociceptive input pain signals conveyed by smaller fibers.
2. Gating mechanisms. There is evidence that descending pain controlling centers (brainstem, mesencephalon, thalamus and hypothalamus) are activated and help suppress pain transmission in the dorsal horn¹⁰.
3. A few studies suggest the possible production of endogenous opioids,

neurotransmitters and neuromodulators by DCS¹¹.

4. There is also evidence that DCS causes vasodilation and alters autonomic (namely sympathetic) activity¹².

Cautions

Though there is evidence from randomized controlled trials^{13,14} that DCS is beneficial, patient selection is extremely important. It is estimated that up to one third to one half of patients implanted with permanent systems will ultimately fail therapy. Surgical indications and patient expectations should be clarified prior to committing to this form of neuromodulation therapy. ■

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