

Excellence in Clinical Neurosurgery: Practice and Judgment Make Perfect

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Having discussed the importance of excellence in research in neurosurgery in my previous lecture, I will now make a strong case for the pursuit of excellence in clinical neurosurgery. Here, the adage “practice makes perfect” will be used time and again to underscore the important roles of repetition of manual and intellectual tasks to achieve excellence in our subspecialty. To this adage, however, I have also added the concept of “judgment,” which comes into play whenever we look after our patients with neurosurgical disease. It takes judgment to know when to operate, but perhaps more important, when not to operate. Even the most skillful technical neurosurgeons run the risk of unexpected patient outcomes if good judgment is not applied to the patients on whom they operate. It is the combination of practice and judgment that perhaps sets us apart as neurosurgeons from other professionals in which a lapse in judgment in their disciplines would not have the far-reaching ramifications that it does for us and our patients. Some of the other disciplines I will be reviewing here in terms of practice making perfect include performance piano and professional tennis and golf as examples.

EXCELLENCE IN EPILEPSY SURGERY

To begin, I will discuss a clinical area of interest to which I have devoted myself for more than a decade, namely pediatric epilepsy surgery. At the outset, I would like to acknowledge the tremendous talents of the personnel within our comprehensive epilepsy center at the Hospital for Sick Children. The workup and investigation of a child with intractable epilepsy include a detailed neurological examination, an electroencephalogram, prolonged video electroencephalographic recordings in an epilepsy monitoring unit, myriad imaging studies,¹ including computed tomography (CT), magnetic resonance imaging (MRI), MR spectroscopy, magnetoencephalography (MEG), PET, single-photon emission CT, diffusion tensor imaging, neuropsychological tests, neuropsychiatric assessment, and neurosurgical consultation.

In broad terms, candidates for epilepsy surgery include those with lesional epilepsy and those with nonlesional epilepsy.² As a general rule, for lesional epilepsy, a reasonable first step is lesionectomy. Occasionally, awake craniotomy or invasive monitoring with subdural grid electrodes for further brain mapping is required, especially if the lesion is found close to or within the language networks in the dominant hemisphere. For nonlesional epilepsy, invasive monitoring is recommended if the epilepsy can be lateralized to 1 hemisphere. If the epilepsy is diffuse or bihemispheric in onset, then palliative epilepsy surgery procedures such as corpus callosotomy or vagal nerve stimulation are often recommended.

The field of lesional epilepsy surgery is made up of conditions that span the entire spectrum of congenital and acquired lesions that affect the central nervous system. These conditions include tumors such as astrocytoma, ganglioglioma, and oligodendroglioma; vascular malformations, including arteriovenous malformations, cavernous malformations, and Sturge-Weber syndrome; malformative lesions such as cortical dysplasia, tuberous sclerosis, neuronal migration disorders, and hemimegalencephaly; cystic lesions such as arachnoid cysts or neuroglial cysts; infectious etiologies, including bacterial, viral, or parasitic; mesial temporal sclerosis; posttraumatic epilepsy; and Rasmussen encephalitis.

If invasive subdural grid monitoring is being contemplated for epilepsy surgery, then it is important ab initio to be cognizant of the benefits and risks of this procedure. In this regard, we have reviewed our experience with subdural grid monitoring at the Hospital for Sick Children.³ There are a few relevant risks with these procedures, including blood loss requiring blood transfusion, cerebral edema, postoperative extra-axial hematoma formation, cerebrospinal fluid leak, and infection.³ To create the optimum neurosurgical plan that can be readily followed by the epilepsy team, we have also found the use of digital camera photography during surgery to be of great value in capturing subdural grid location and determining the relationship between proposed resected regions to eloquent brain and critical vascular structures (Figure 1).⁴

With a subdural grid in place, extraoperative monitoring is conducted to capture the ictal onset zone during stereotypical seizure semiology. After identification of the

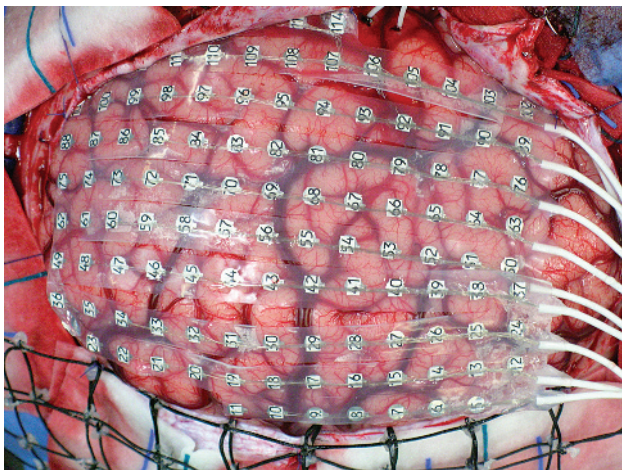


FIGURE 1. Digital camera intraoperative photograph showing the exposed surface of the brain and a subdural grid in place. Such digital photographs have become a routine part of epilepsy surgery programs whereby they can be used to prepare a map of the neurosurgical procedure that will follow once the ictal onset zone has been captured.

ictal onset zone and surrounding zones of primary epileptogenesis, we can create a seizure map for the patient (Figure 2). Using computer software drawing programs, we can produce an epilepsy surgery plan that will demarcate the zone of resection; the regions of brain eloquence, including motor,

sensory, and language functions; and the spread of seizure activity throughout the brain. Recently, we have developed a computer animation program based on high-frequency oscillations that allows us to visualize the spread of a seizure from the ictal onset zone through adjacent neural networks to other regions of the brain.⁵

At the Hospital for Sick Children, we have extensive experience with MEG in the workup of the child with epilepsy.⁶⁻¹² MEG represents a novel technology that maps interictal epileptogenic spike sources onto an MRI scan (Figure 3). At our institution, we have characterized the number of spike sources that are critical in forming a typical spike cluster.¹¹ A spike cluster is defined as > 20 spike sources within a 1-cm² distance. It is our firm belief that such tight interictal spike clusters correlate with ictal onset zone in the majority of cases and can predict the site of neurosurgical resection required for seizure-free outcome. Recently, we have combined the utility of 3-dimensionally reconstructed MEG spike source localization on MRI with intraoperative neuronavigation to assist with neurosurgical planning and extent of resection of the seizure focus.¹⁴ Several cases outlined below illustrate the power of MEG technology in pediatric epilepsy surgery.

We have seen children with convexity arachnoid cysts and epilepsy in whom an MEG spike cluster is found adjacent to the cyst, a finding that may indicate an irritative focus caused by local pressure by the cyst (Figure 4). After craniotomy and evacuation of the arachnoid cysts, these children can be made seizure free and taken off their preoperative seizure medications. In the case of Rasmussen encephalitis, children usually present with epilepsy partialis continua. Their MEGs will typically demonstrate an ictal onset zone (Figure 5). Of course, MEG technology will advance substantially if all patients with epilepsy had a seizure while undergoing MEG, much the same way as ictal positron emission tomography or single-photon emission CT can be very useful in the management of patients with epilepsy. In select cases in which there may be a contraindication to invasive monitoring to map out the seizure onset zone, we have proceeded directly to craniotomy for resection of an MEG spike, a so-called “clusterectomy” (Figure 6). Finally, in the setting of status epilepticus, a neurological emergency that has high morbidity and mortality rates, an MEG may demonstrate localization of MEG spike cluster activity, usually ictal in origin, which may identify patients who would benefit from surgery to eliminate the seizure focus (Figure 7) and to be discharged from the intensive care unit in good condition.¹⁵

With MEG, we can now map various cerebral functions onto an MRI. For example, the visual evoked field can now be identified on MRI following a light stimulation paradigm (Figure 8). Recently, we have used MEG to map the motor cortex of the brain.¹⁶ Here, we studied the presurgical localization of the primary motor cortex in pediatric patients with brain lesions using spatially filtered MEG (Figure 9). We predict that the entire motor homunculus will soon be mapped by MEG.

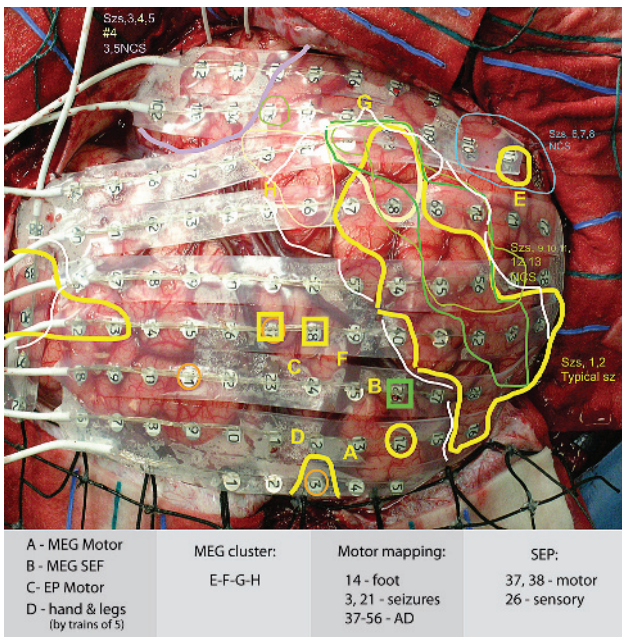


FIGURE 2. Epilepsy surgery map prepared with computer software programs that enable the drawing of the proposed resection on the image and the functional zones of the brain. MEG, magnetoencephalography; EP, evoked potential; SEP, somatosensory evoked potential.

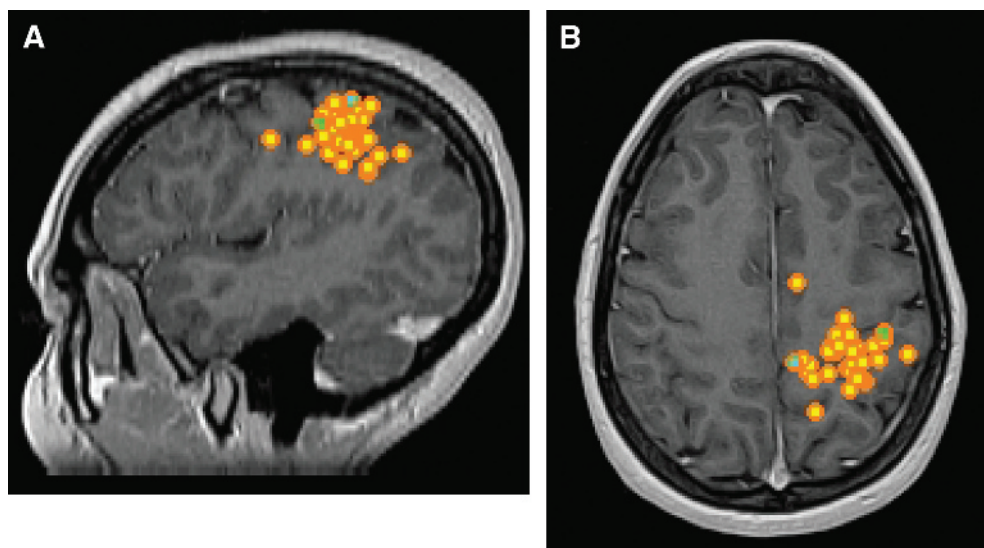


FIGURE 3. Sagittal (left) and axial (right) magnetoencephalography showing interictal spike cluster in the somatosensory cortex of a 16-year-old girl with intractable epilepsy.

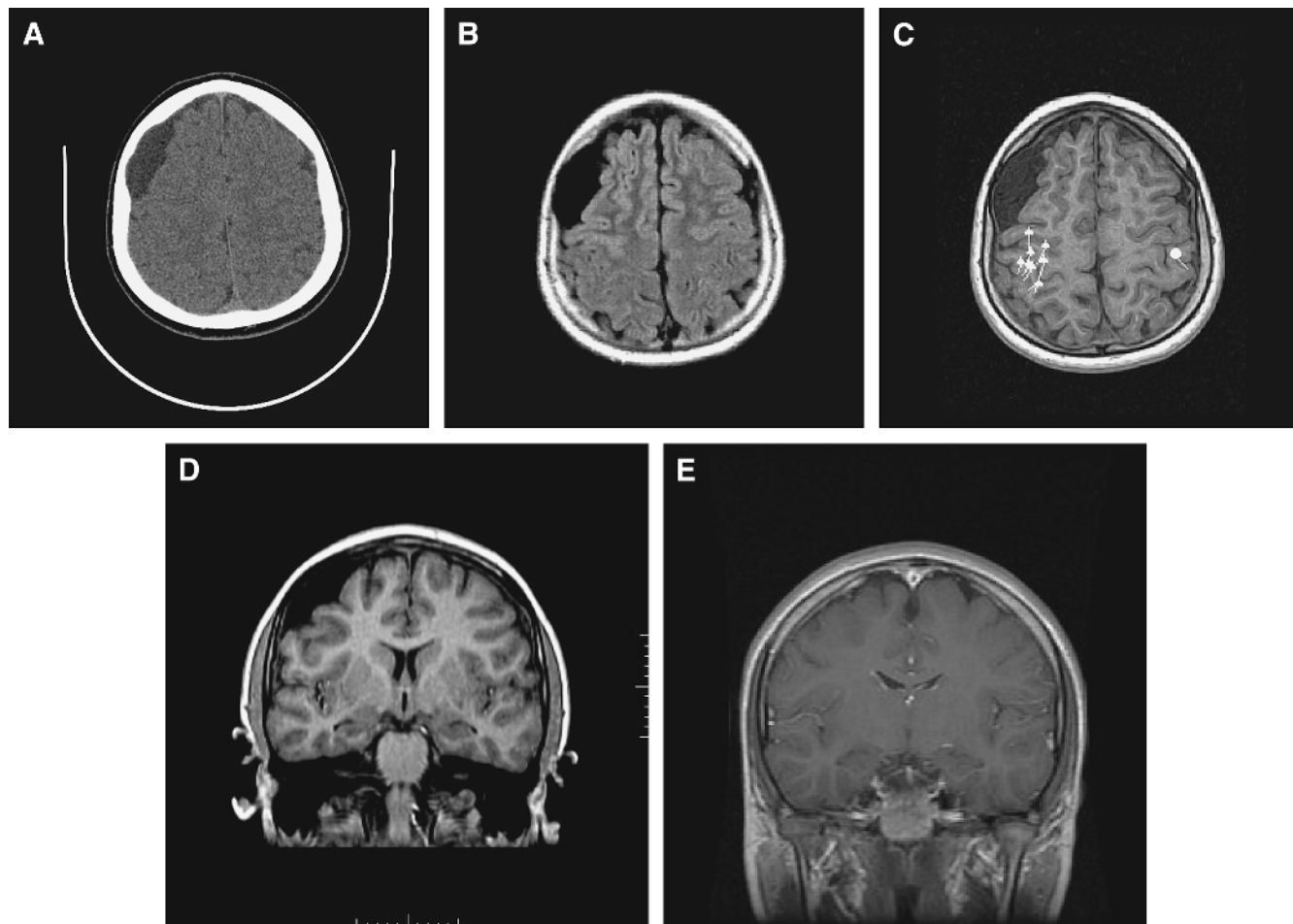


FIGURE 4. Right convexity arachnoid cyst in a 14-year-old boy. A, axial computed tomography (CT) depicting location of cyst and remodeling of overlying skull. B, axial magnetic resonance imaging (MRI) at the same cut as the CT showing extrinsic compression by the cyst on the underlying brain. C, axial MEG showing a spike cluster in the region of the right motor cortex. D, coronal MRI showing preoperative localization of the arachnoid cyst. E, postoperative coronal MRI showing obliteration of the cyst. The child is now seizure free and off medications.

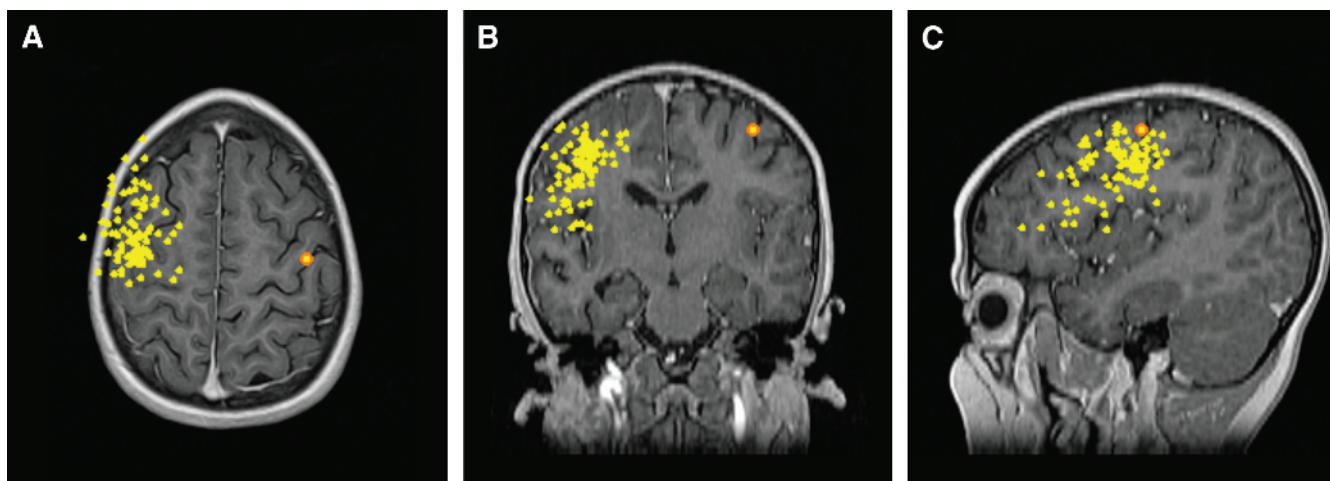


FIGURE 5. Rasmussen encephalitis in a 6-year-old boy. Left (axial), middle (coronal), and right (sagittal) magnetoencephalography (MEG) showing central extensive ictal spike cluster. Although MEG typically identifies interictal spike wave abnormalities, in the context of Rasmussen encephalitis and epilepsy partialis continua, this can often be an ictal MEG demonstration.

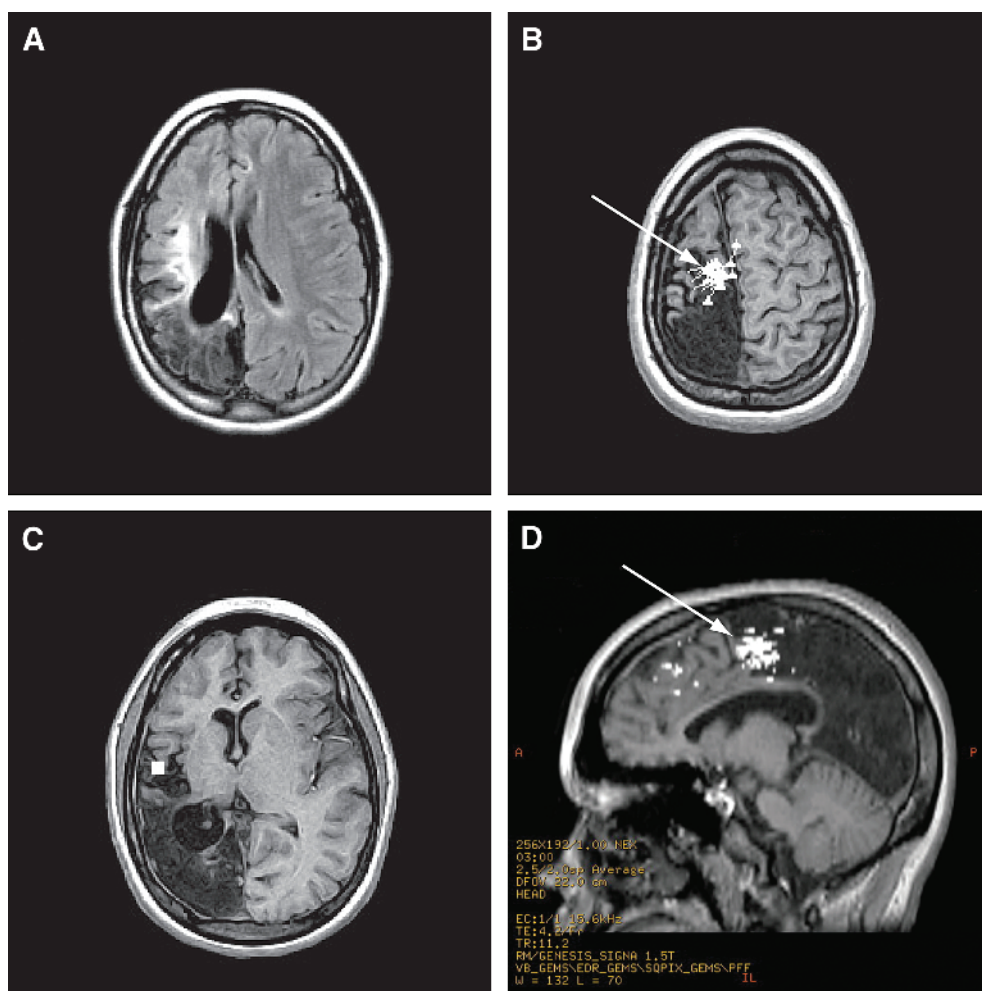


FIGURE 6. Demonstration of an magnetoencephalography spike cluster in a 16-year-old girl with intractable epilepsy. The prior area of encephalomalacia related to remote trauma is seen posterior to the spike cluster. This patient underwent “clusterectomy,” which led to the elimination of seizures and reduction in seizure medications.

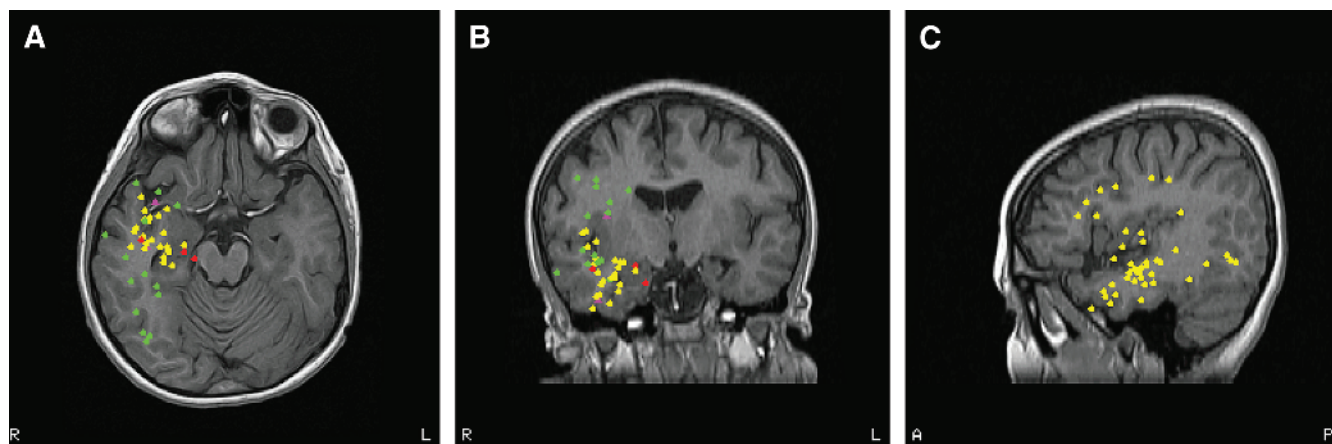


FIGURE 7. An 8-year-old boy with status epilepticus. Axial (left), coronal (middle), and sagittal (right) magnetoencephalography showing a spike cluster affecting primarily the right temporal lobe. The patient had *epilepsia partialis continua*. He underwent a temporal lobectomy. He could then be extubated and taken to the ward. He now has rare seizures and is functioning at a normal level in school.

In our comprehensive epilepsy center, we have combined the techniques of MEG, invasive subdural grid monitoring, and functional brain mapping to perform neurosurgical resections of epileptogenic lesions in the Rolandic area of the brain.¹⁷ We studied a series of 22 patients with intractable rolandic epilepsy and reported that their outcome after neurosurgical resection was 64% in Engel class I, 18% in Engel II, 9% in Engel III, and 9% in Engel IV. Of note, 20 of 22 patients had > 90% decrease in seizure frequency.¹⁷ These are among the most difficult children with epilepsy to treat because of the potential risk of functional impairment affecting motor hand or leg after surgery.

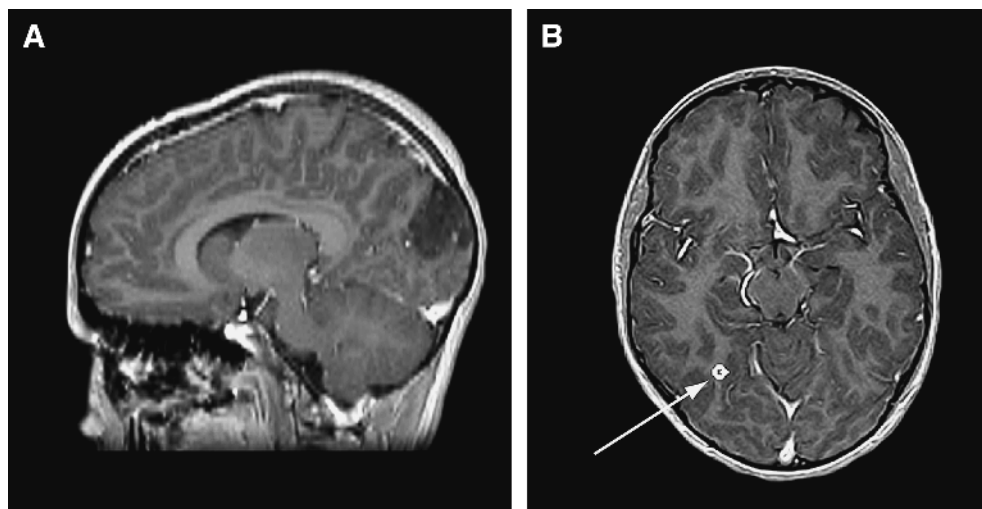
An expanding repertoire of neurosurgical procedures can be performed on children with epilepsy. These procedures include temporal lobectomy for tumors, mesial temporal sclerosis, or cortical dysplasia^{18,19}; corpus callosotomy^{20,21};

vagal nerve stimulation²²; and hemispherectomy.²³ As for hemispheric disorders for which hemispherectomy is indicated, these include Sturge-Weber syndrome, hemispheric cortical dysplasia, hemimegalencephaly, and Rasmussen encephalitis.

WAYS IN WHICH PRACTICE MAKES PERFECT

As with many areas of neurosurgery, the art of epilepsy surgery requires practice to improve on one's results. Just as it takes skill and dexterity to deftly remove a parafalcine meningioma from a finite intraoperative corridor between the optic nerve and intracranial carotid artery, so it takes excellent technique to cleanly and sharply microdissect the interhemispheric plane down to the pericallosal arteries to effectively perform a corpus callosotomy. Similarly, the removal of

FIGURE 8. Demonstration of the visual evoked field (VEF) by magnetoencephalography (MEG). Sagittal magnetic resonance imaging (left) shows an occipital lesion causing epilepsy in a 9-year-old boy. An axial MEG (right) shows the VEF (arrow), which helps the neurosurgeon plan surgery to avoid the calcarine cortex using neuronavigation linked to the data from the MEG. The lesion proved to be a dysembryoplastic neuroepithelial tumor. The child is well without seizures or tumor recurrence postoperatively.



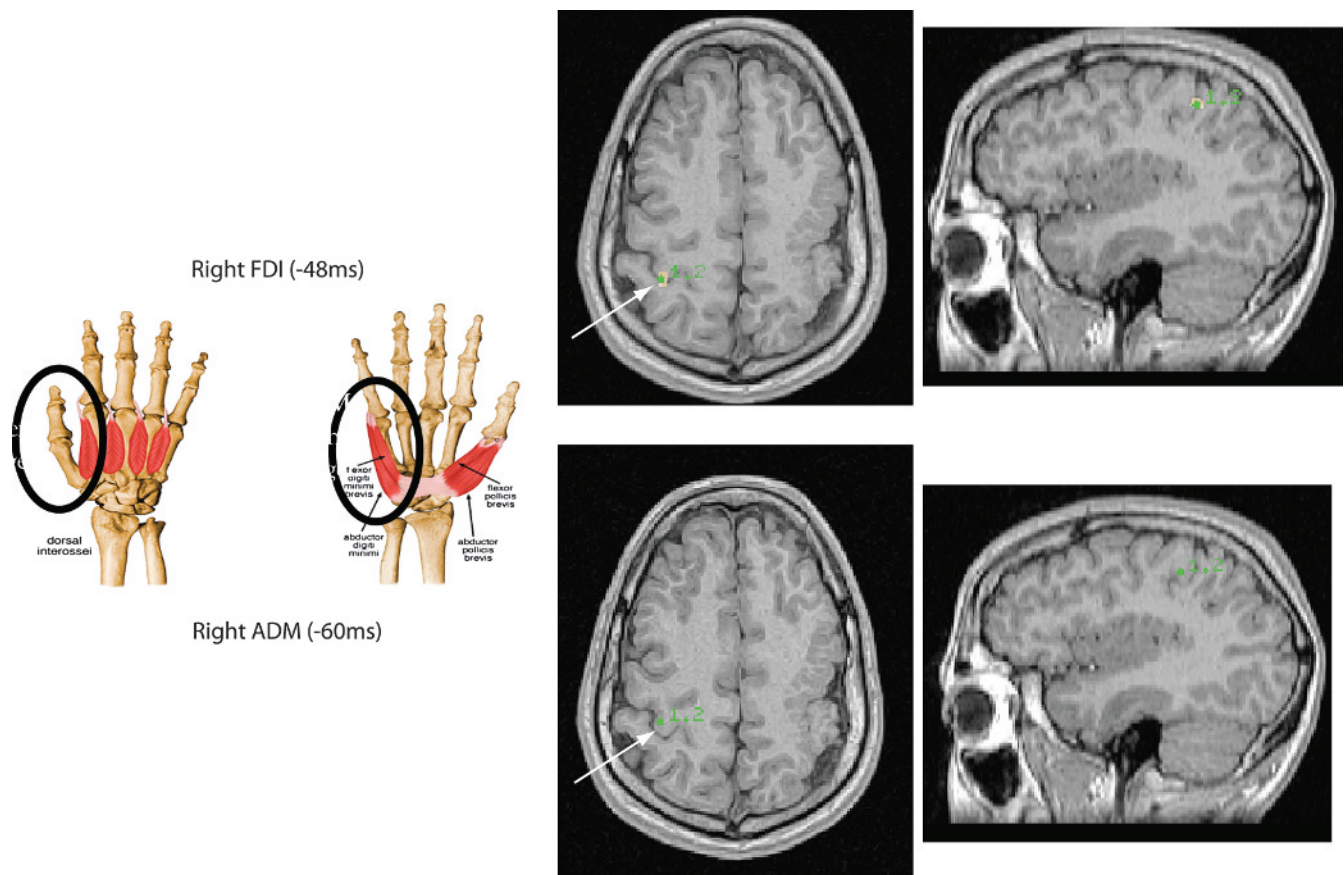


FIGURE 9. Mapping the motor cortex by magnetoencephalography (MEG). The flexor digiti indicis (FDI) and the abductor digiti minimi (ADM) can be stimulated using appropriate paradigms to map the motor cortex using MEG as shown. Soon the entire homunculus will be mapped in this manner by MEG.

a dominant hemispheric sylvian epidermoid tumor requires patience, vigilance, and excellence in technique to micro-dissect the tumor away from the branches of the middle cerebral artery. Famed professional violinist Jascha Heifetz once stated, “If I don’t practice one day, I know it; two days, the critics know it; and three days, the public knows it.” Former Green Bay Packer professional coach Vince Lombardi is quoted as saying, “It is not practice that makes perfect; it is perfect practice that makes perfect.”

Take the case of piano virtuoso Glenn Gould, who was born in Toronto, who devoted his life to mastering the piano, and who developed an idiosyncratic style with which to play the piano (Figure 10). For example, he typically sat on a low chair with a high back, his elbows at a level below the keyboard, and he played with powerful fingers with left-hand dominance. He performed 24 takes of the aria from the Goldberg variations before he was satisfied that his recording was “perfect.” He was generally considered eccentric and indeed was reclusive in later life. Still, his interpretations of keyboard works by Bach, Beethoven, and Schoenberg are considered the best the world has heard. To achieve greatness



FIGURE 10. Virtuoso pianist Glenn Gould at the piano. Note his rather unorthodox piano playing style. Gould sat at the piano on a low chair with a high back. His elbows were typically below the keyboard, and he played with powerful hands and left-hand dominance.

at the piano, Gould was disciplined with practice from a very early age.

Or take for example the incredible athletic abilities of Roger Federer, famed tennis player, whose tennis form is considered the best the world has seen. Federer was born in Binningen, Switzerland, in 1981, and played tennis seriously from 8 years of age. An all-court player, Federer shows uncommon strengths in all aspects of the game, including his serve, volleys, backhand, and forehand. He currently holds the world Grand Slam record in tennis. Part of the reason for Federer's success has been his attention to his fitness schedule and the discipline with which he approaches practice. As Marat Safin once stated, "Roger Federer is definitely the best tennis player of all-time. He is the perfect tennis player. Some are great physically, some mentally, and others technically. Roger is all of them."

Few of us will forget the incredible birdie at the 16th hole of the 2005 Masters Golf Tournament in Augusta where Tiger Woods performed an incredible chip shot off the green into the cup. Born in 1975 in California, Tiger Woods was a child prodigy at golf and began to play the sport at 2 years of age. He was a 6-time winner of the Junior World Championships and enrolled at Stanford University, where he was educated for 2 years. He has a powerful drive off the tee, and his success relates to his phenomenal consistency from round to round. This consistency stems not only from innate and natural talent in golf but also from a rigorous practice schedule that has enabled him to perfect his game.

These examples of high achievers in piano performance, tennis, and golf illustrate the importance of practice. Recently, emphasis has been placed on the achievement of superior performance through deliberate practice.²⁴ Ericsson and colleagues²⁴ have written that it is deliberate practice in a noncritical environment that enables professionals to achieve at a high level. Once a particular task has been perfected, the superior performer will take on the next challenge. It is now clear that repetition facilitates muscle memory for complex tasks. However, the journey to becoming an elite performer is not for the faint of heart. Generally speaking, it takes at least a decade and guidance from an expert teacher who provides tough but well-directed feedback.²⁴ After the achievement of success in a given field, experts are able to develop an inner coach to drive their own progress. This analysis is similar to what has been described in the book *The Outliers* by Malcolm Gladwell, who has popularized the "10 000 hours rule" for those seeking to be successful in any given discipline.²⁵

PRACTICING NEUROSURGERY: THE SHAPE OF THINGS TO COME

In the Division of Neurosurgery at the University of Toronto, each year we offer several hands-on courses to our residents so that they can practice their neurosurgical skills in

a noncritical environment. These courses have included epilepsy surgery, microvascular neurosurgery, spine surgery, peripheral nerve surgery, and neuroendoscopy. The future of neurosurgical training may require the art of simulating neurosurgery in a way we can only imagine today. In the past, neurosurgical training revolved around teaching on a cadaver model, which had benefits from an anatomical standpoint but also limitations in terms of cost and inability to recapitulate the live, human condition. Interestingly, the National Research Council of Canada has developed a brain surgery simulator for the removal of brain tumors. The simulator experience recapitulates the intraoperative procedure complete with haptics, pulsating brain, and bleeding from arteries and veins (<http://www.nrc-cnrc.gc.ca/eng/news/nrc/2009/08/26/virtual-surgery.html>). In this simulation model, preoperative information from a patient with a brain tumor is transferred to the simulator workstation, and it is rendered real using a transformation of the data points to a cartoon animation platform. Using this simulator, neurosurgery residents can learn how to use the Cavitron in the removal of a brain tumor just as would be performed intracranially on the patient. The procedure could be rehearsed, for example, the night before the operation is performed. These and other sophisticated models of neurosurgical simulation will undoubtedly be developed in the near future to serve as new training tools for neurosurgery residents.

IF PRACTICE MAKES PERFECT, THERE MUST BE TIME TO PRACTICE

The path to success in neurosurgery can be a long and winding road. If one tabulates the number of years to be educated and trained to be a neurosurgeon, it amounts to almost 20 years. This includes 4 years as an undergraduate, 4 years in medical school, 6 to 8 years in neurosurgery residency, 1 year as a clinical fellow, and 1 to 2 years in research training. Typically, the years spent in residency are the most difficult in terms of hours spent. However, there has been a recent trend to reduce the number of work hours that residents will spend on a neurosurgery service. These reductions are being instituted by governmental forces. In Canada, there are no work-hour restrictions for residents; in the United States, neurosurgery residents are being restricted to work 80 hours per week. In other countries around the world, surgical residents may work on average 70 hours in Ireland, 60 hours in Brazil, 54 hours in Great Britain, 60 hours in Switzerland, 42 hours in Denmark, and 35 hours in France (Richard Reznick, personal communication, May 2009). It is difficult from my perspective as chair of a major neurosurgical program to imagine effectively training a resident to full competency and excellence with restrictions placed at 40 hours per week on a busy neurosurgical service.

When one analyzes the current forces at play in postgraduate education, the effects on resident training are

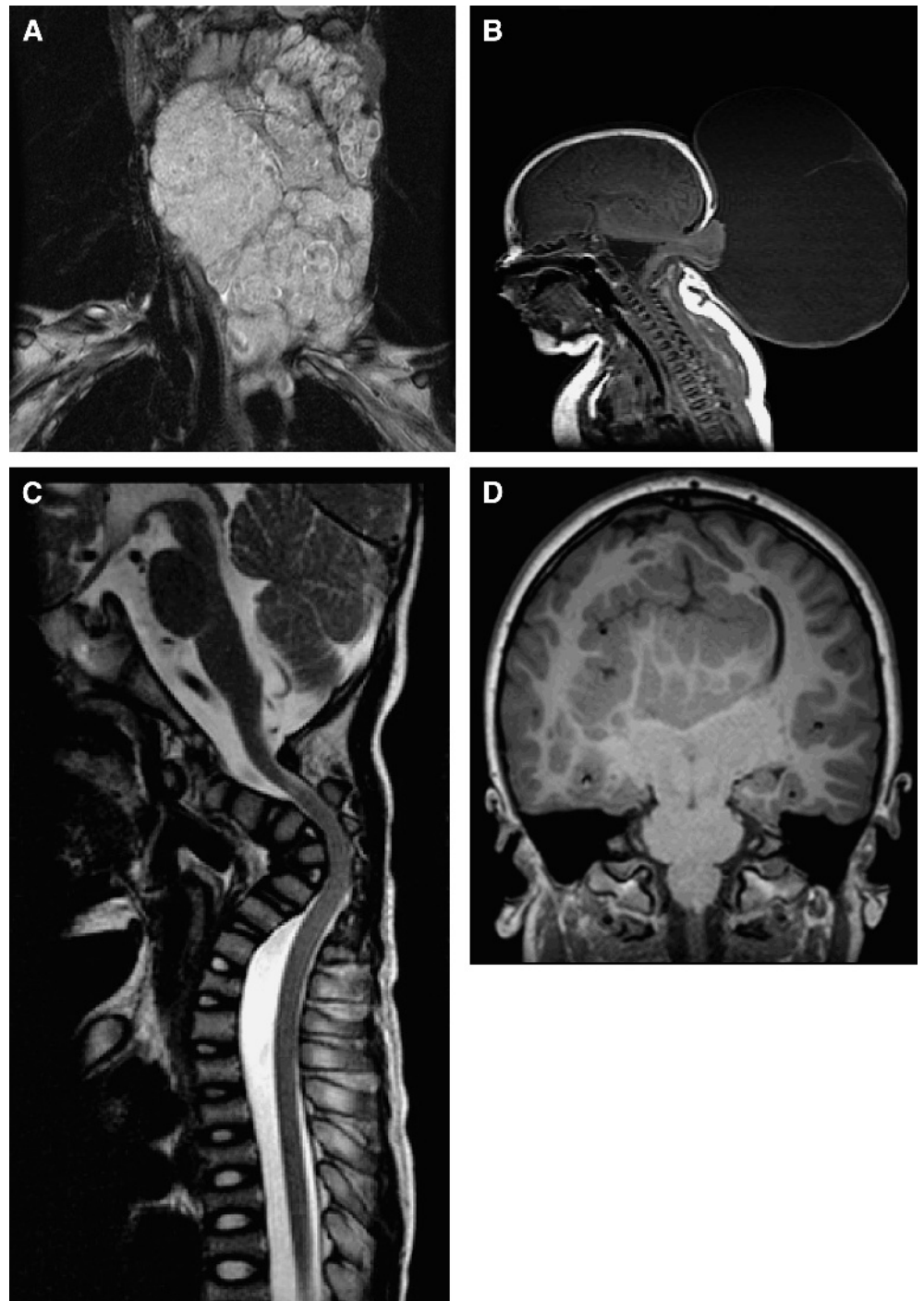


FIGURE 11. Judgment in neurosurgery, or when not to operate. A, a coronal cervical magnetic resonance image (MRI) showing massive plexiform neurofibroma occupying the entire neck. This patient had noisy breathing only. B, sagittal MRI in newborn baby showing large encephalocele sac with brainstem and cerebellum coming into the sac. The baby died within days of birth because of the severity of the lesion. C, underlying fatal skeletal dysplasia in an infant with profound cervical kyphosis on sagittal MRI. The natural history of a child with this condition is unfavorable, with death seen in the vast majority of cases before 2 years of age. D, rare seizures were found in this child with massive intraventricular heterotopic grey matter on coronal MRI.

sobering. Fiscal restraints, growth of knowledge, and influences from society have led to pressure for speed in the operating room, the performance of increasingly complex cases, a demand for patient safety, a limitation on medical errors, and a higher degree of stress among faculty and residents. The result is a loss of significant clinical opportunities for neurosurgery residents to attain excellence in clinical neurosurgery.

Potential solutions to these problems include tackling politics and finances head on. We should not be complacent in accepting governmental solutions to resident training if in the end our patients will suffer because of an ill-equipped or substandard workforce. We should accelerate the pace of procedural skill acquisition. We must diminish time wasted on the clinical services through support services that can reduce

the noneducational workload of neurosurgery residents. We should continue to evaluate our residents throughout their training—often and objectively. And finally, we must develop and promote a culture of collegiality (Richard Reznick, personal communication, May 2009).

As some of the first steps to achieving excellence in clinical neurosurgery, checklists have now been developed to help surgeons, nurses, and anesthesiologists reduce failures in the operating room.²⁶ This change has already led to substantial improvements in minimizing errors in the operating room. In addition, many centers have implemented a “timeout” strategy in which the goals of the operative procedure and the expectations during surgery are recounted by the operating team.

EXCELLENCE IN CLINICAL NEUROSURGERY: YOU MAY FIND THESE POINTS HELPFUL

Here are some of the strategies I have found useful in pursuit of excellence in clinical neurosurgery. First, know your neuroanatomy. There is no substitute for this. Second, spend time positioning your patients perfectly for neurosurgery. Third, avoid brain retraction, which can lead to brain injury. Fourth, always think 2 or more steps ahead, and rehearse the case in your mind before you perform the procedure. Fifth, use 2 hands in a coordinated fashion to operate. In many instances, the suction and the bipolar cautery are the main instruments that should fit comfortably into the hands of a neurosurgeon. The excellent neurosurgeon will be adept at using both instruments in either hand, depending on the situation. Sixth, stay calm under pressure; never become angry. And finally, use economy of movements and continue to hone your neurosurgical skills with every case. In preparing for this lecture, I had an opportunity to review rare video footage of Dr. Harvey Cushing operating in the 1930s. He was a meticulous neurosurgeon with an immutable routine. His line of sight rarely changed throughout the case once he was operating. There is no question that our neurosurgical routine is an amalgam of nuances and trade secrets learned from our mentors.

Other neurosurgical strategies you may find of value include reviewing video footage and photographs from your operative procedures to improve your performance; dictating all operative notes immediately after the case; speaking to patients and their families after the case is completed; facing your unexpected outcomes with integrity and honesty; and having a conscience to know when it is best to investigate the patient, worry about their complaints after surgery, or decide when it is best to go back to surgery. Of course, proper implementation of these points requires the use of good judgment to improve patient outcomes. Jim Horning once said, “Good judgment comes from experience. Experience comes from bad judgment.” Also, one should remember that “humility is just one bad case away.”

In neurosurgery, it is not so much the arteries but the cerebral veins that can get you into trouble. When operating deep in the ventricular system, for example, one should always be aware of manipulation of the deep venous drainage system. Sacrifice of one or both internal cerebral veins could have disastrous consequences for the patient. When deciding on a neurosurgery trajectory to a lesion, one should usually select the most direct approach. And this should be commensurate with the neurosurgeon’s experience and preference for this approach. Sometimes, it is of value to know when to stage long neurosurgical procedures. Sometimes, less is more. For example, in the face of a highly malignant disease such as spinal cord glioblastoma, attempts at radical resection are not in the patient’s best interest. Sometimes, however, more is better. As a general principle, cytoreductive surgery makes good sense from an oncological perspective as long as aggressive surgery is accompanied by preservation of the patient’s functional status. Finally, we must recognize that there are diseases in which neurosurgical treatment may render the patient worse off than the natural history of the disease. Examples (Figure 11A through 11D) include a massive cervical plexiform neurofibroma involving the entire cervical region in which the patient’s only complaint is loud breathing (Figure 11A); an occipital encephalocele in which the brainstem and cerebellum are located within the sac outside the posterior fossa (Figure 11B); an underlying fatal skeletal dysplasia in a baby with a profound cervical kyphosis that would be difficult to correct even in a healthy, mature child (Figure 11C); and infrequent seizures in a child who is well controlled on anticonvulsant monotherapy who has a major neuronal migration disorder and massive heterotopic gray matter within the ventricular system (Figure 11D).

CONCLUSION

As with performance piano playing, sports athletes, aviators, and gymnasts, for neurosurgeons, practice can make perfect. But the practice of neurosurgery should be accompanied by sound clinical judgment for the right decisions to be made within and outside the operating room for our patients. There is no substitute for knowing our neuroanatomy. Frequent review, hands-on courses, and performing new procedures will keep us sharp and on top of our game. Deliberate practice in a noncritical environment will be demanded not only by our patients but also by society, so advances in processes such as neurosurgical simulation may play a big role in neurosurgical education in the future. Always listen to your conscience and learn from your mistakes. And finally, remember that “great surgeons are not born, rather they are made by a commitment or willingness to pay the price for excellence.”

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