Approximately 70% of childhood seizures can be treated successfully with medications. For the 30% of patients who are truly refractory to medical treatment—that is, who have had adequate trials with the appropriate medications—surgery may be an option for controlling the seizures. This article will review how surgical candidates are evaluated and how the surgical approach is tailored to the problem of the individual patient.

PRESURGICAL EVALUATION: DEFINING THE SEIZURE FOCUS

For the patient deemed intractable to medications, a range of tests can be used to determine if the seizures are originating in one specific area of the brain. Are they focal seizures? Are they starting regionally, from within an entire hemisphere, or bilaterally? Answers to these key questions in the presurgical evaluation are critical because they will shape the surgical approach.

A patient with focal onset seizures, for example, may be a candidate for focal resection. In general, patients with a smaller and well-defined seizure focus have a better chance of becoming seizure-free after a lobectomy or lesionectomy. If the focus is located in the eloquent cortex or in an area of motor control, a focal transection involving multiple subpial transections (surgical cuts through the epileptic region) may be more appropriate. With newer imaging and electroencephalogram (EEG) recording techniques, many epilepsy cases formerly thought of as diffuse are now found to result from a single focus that quickly propagates throughout the brain. Patients with such seizures are also now candidates for focal surgery.

Surgery may still be possible for patients who do not have a true focus, and suitability for these procedures is still determined by presurgical testing. For example, patients with widespread onset of seizures might be candidates for corpus callosotomy or for the less invasive surgical alternative of vagal nerve stimulation. For the small group of patients with widespread, unilateral onset of epilepsy, a hemispherectomy can provide valuable relief.

EEG STUDIES

The search for a focus is carried out mainly with the EEG and imaging studies. To localize the area of seizure onset, basic EEG monitoring often includes extra scalp electrodes along with the standard 10/20 system electrodes. In some patients, this noninvasive scalp EEG is sufficient to determine the lobe of seizure origin and the extent of involvement.
In other patients, a variety of implanted electrodes may be required to record activity from the surface of the brain or from within the cortex. Subdural or depth electrodes can be deployed depending on the main goal of the inquiry. For example, subdural electrodes are useful in investigating the neocortex because a greater number of electrodes can be spread widely over an area of concern. Similarly, when planning to perform extraoperative testing of motor, sensory, or language function, subdural electrodes are probably most useful. These electrode arrays come in a variety of shapes and sizes and are selected and positioned by surgeons according to the patient’s need (Figure 1).

If the epileptologist is interested in exploring the medial cortical regions, in particular the hippocampus and amygdala, depth electrodes allow a more direct analysis of the area of concern. Depth electrodes are basically long wires with metal contacts along their shafts. They are positioned in the brain using 3-dimensional stereotactic techniques, with insertion through a firm sleeve that is removed before analysis (Figure 2). In some cases, patients need a combination of depth and subdural electrodes to determine the location and extent of the seizure activity.

In general, the goal is to record seizures simultaneously on EEG and videotape. The epileptologist can then analyze the EEG and clinical characteristics of the seizures and try to determine the site of seizure onset.

**IMAGING**

Magnetic resonance imaging (MRI) tests can be used to determine hippocampal volume and similar structural measurements to delineate areas of brain abnormality. Some patients also have completely separate areas of dysplastic tissue that may require excision to control the seizures.

To increase the probability of finding all the relevant underlying epileptogenic abnormalities, several other imaging techniques can be employed, when needed, in the presurgical evaluation. These include magnetic resonance spectroscopy (MRS), which detects abnormalities in brain metabolism, and positron emission tomography (PET). This latter technique provides an indirect measurement of epileptogenesis by indicating areas of hypometabolism. While the actual area of seizure onset may be
smaller than the PET-highlighted area, the test remains useful in narrowing the search area. New MRS and PET based methods as well as functional MRI may eventually increase the precision of these methods.

Ictal single photon emission computed tomography (SPECT) assesses blood flow during seizures. Clinicians need to realize, however, that ictal SPECT requires that the imaging agent be administered and the images captured while the seizure is still active, and preferably immediately after the onset of EEG evidence of a seizure. With existing techniques, such prompt administration and monitoring entail considerable planning and bedside readiness. To facilitate this, our institution has mechanized and automated the injection of the contrast agent with a Harvard pump.

Overall, the presurgical analysis involves a stepwise approach. First, less invasive methods are employed. If these fail to provide answers, then depth or subdural electrode placement may be considered. No single technique is appropriate for all patients.

**SURGICAL OPTIONS**

The perpetual challenge in epilepsy surgery is removing as little tissue as necessary while still providing the maximum relief from seizures. This difficult balancing act drives the surgical decisions in virtually every epilepsy procedure.

In an amygdalohippocampectomy, for example, removal of the mesial temporal structures is common, but portions of the neocortex may or may not need to be removed. In some cases, microsurgical removal of the hippocampus and the amygdala can produce seizure-free outcomes. In other cases, areas of adjacent or even nonadjacent neocortex need to be removed to prevent seizures over the long term. Invasive electrodes can be used to help clarify the question of how much to remove (see “Drawing a Better Dotted Line”).

Various surveys of the surgical treatment of epilepsies indicate that about 50% to 70% of patients become seizure-free after temporal lobectomies. Approximately 10% to 40% of patients show some improvement, while 10% to 20% do not improve.

Seizure control is often not as good after extratemporal resections. However, improved imaging and EEG recording now allows identification of neocortical dysplasias and areas of abnormal migration, and these more refined neural maps have greatly assisted surgical planning and led to improved surgical outcomes. Surgical alternatives to resection have also provided new options for patients with epileptogenic activity originating diffusely or in extratemporal areas of the brain.

Performance of multiple subpial transections is a surgical technique used when functional mapping of the cortex reveals an area of seizure onset directly within an area controlling an important function, such as the primary motor area. With this technique, the cortex is separated, or combed apart, with a methodical series of small, subpial cuts. The original rationale for the procedure was to separate adjacent cells and thereby make
it more difficult for them to propagate seizures, essentially by “cutting the wires” that cells use to communicate with each other. Multiple subpial transections may also work by lysing cells within the area of each cut, thus creating a series of breaks in the neuronal communication system. Neurons deep within microsulci are not altered by the transaction, and these may be sufficient to maintain normal cortical activity. Pre- and intraoperative mapping is now routinely used to guide subpial transections. Overall, about 70% of patients undergoing multiple subpial transections have improved control of seizures. However, some experience difficulties with the functions controlled by the transected cortex.

Hemispherectomy is appropriate in a small group of children with widespread but one-sided areas of epileptogenesis. These surgical candidates often present with loss of movement and sensation on one side of the body. They are often hemiplegic by the time of surgery and have typically not responded to any medications. Many have Rasmussen’s syndrome, Sturge-Weber syndrome, or other developmental disorders. Despite removal of half of the cortex, the improvement is often dramatic. Approximately 60% to 80% of these children become seizure-free, and many regain the ability to walk or run. Intellectual function may also improve. The potential risks of hemispherectomy are considerable, as these patients are at risk for bleeding into the subarachnoid tissues with resulting hemosiderosis or hydrocephalus, but most do well.

Corpus callosotomy, which involves severing the neural connections between the right and left hemispheres, is generally reserved for patients with widespread seizure discharges, particularly patients with tonic or falling seizures, tonic-clonic seizures, and for specific epilepsy types such as Lennox-Gastaut syndrome. Only about 10% of patients having corpus callosotomy become seizure-free, but up to 70% can improve. The technique is especially useful in preventing falling seizures. Unfortunately, in some cases, this procedure may also actually worsen seizure activity and diminish intellectual function.

These poor outcomes are postulated at times to be caused by the removal of a natural seizure inhibitory action that one side of the brain exerts on the other. When the corpus callosum is cut, this natural inhibition is lost and the number of focal seizures initiated may grow. For this and other reasons, patients often are considered first for the vagal nerve stimulator, which is discussed below.

DEVICES

The vagal nerve stimulator is a surgically implanted device, similar to a cardiac pacemaker, that periodically stimulates the vagus nerve in the neck, which in turn sends bursts of electrical activity to the brain. In ways not yet understood, this stimulation ameliorates epileptogenesis. About 50% to 40% of patients have a decrease in number of seizures by at least half. However, only about 3% or 4% of patients become seizure-free. Antiepileptic medication is typically still required in most patients, but often at lower dose. The vagal nerve stimulator commonly causes a tickling of the throat or coughing. However, when this side effect is explained to the patient and family, the device has been generally well tolerated and accepted by children.

A number of other stimulation techniques are available, all of which are aimed at altering the balance between neural excitation and inhibition, thereby reducing the number or extent of epileptic seizures. Stimulation of the thalamus and of the hippocampus has led to improved seizure control in experimental animal settings and in open-label clinical studies. A multicenter study of stimulation of the anterior nucleus of the thalamus will begin soon.

The thalamic electrodes being tested are identical to those already being employed to treat pain and movement disorders. Experience with these devices for these other indications suggests that a certain level of potentially serious complications should be anticipated in epilepsy treatment. In particular, electrode placement

**DISCUSSION POINT**

“The perpetual challenge in epilepsy surgery is removing as little tissue as necessary while still providing the maximum relief from seizures. This difficult balancing act drives the surgical decisions in virtually every epilepsy procedure.”

Ronald P. Lesser, MD
can cause hemorrhage with serious consequences, such as coma and hemiparesis.

**SUMMARY**

In managing children with epilepsy who are not controlled by medication, the search for a classic seizure focus with a high probability of resection success is a first priority. However, of equal importance is to recall that seizures may originate in more than one place in the brain and, in addition, that seizures could be inhibited by more than one treatment mechanism. In fact, most seizures that remain outside our control are probably caused by multiple pathways and multiple underlying mechanisms. How do we block these multiple pathways? Does a simple common pathway exist that will inhibit more than one mechanism? These are the challenges for the future.

**QUESTIONS & ANSWERS**

Could an alternative pathophysiologic explanation, such as other than the hemispheric inhibitory theory, explain the observation that certain patients develop focal seizures following corpus callosum section?

**Dr Lesser:** Yes, in addition to the hemispheric inhibitory theory, it is possible that these foci were always present, but, before the procedure, their clinical expressions were masked by the rapid appearance of generalized seizures.

**Dr Lassonde:** This reported risk of developing new foci needs more study. Animal evidence actually indicates that transmission through the corpus callosum is excitatory rather than inhibitory. Further, our work with functional MRI in patients who have had the surgery indicates no adverse effects on motor function and some surgeons, such as Dr. Wong in Taiwan, still report satisfactory results with the procedure.

What is the extent of the intelligence quotient (IQ) change after hemispherectomy?

**Dr Lassonde:** As Dr. Lesser described, some improvements in functional intelligence, such as those indicated with attention span and memory, may be seen. Improvements in motor function are also evident. Overall, however, our recent review of the literature indicates no improvement in IQ following hemispherectomy in children. Parents should be aware of this and set expectations accordingly.

**Dr Duchowny:** The prognosis and IQ will also vary depending on etiology. For example, children with bilateral abnormalities rarely improve after hemispherectomy.

What explains varying electrophysiological findings from an area surveyed by simultaneous subdural and depth electrodes?

**Dr Lesser:** The resistivity of the 2 electrode types are different, and that may actually alter the area of the cortex that is being surveyed and recorded. The 2 probes may be relatively close to each other, in the hippocampus and the basomedial neocortex, eg, but the seizures may look different because of the slight differences in location and substrate.

How does the interictal SPECT compare to ictal SPECT?

**Dr Lassonde:** Some clinicians in Paris have recently shown that SPECT in the interictal period can highlight areas of metabolic injury with high precision. Functional MRI is another technique that is quite new but potentially useful.

**Dr Lesser:** Done properly, the ical SPECT works very well and is quite consistent from clinic to clinic. The interictal SPECT requires more subjective interpretation and is therefore less consistently helpful. It is more like a CT [computed tomography] in this respect, with results in the eyes of the beholder. I agree that functional MRI appears very promising.

**Dr Rho:** Some centers are also performing subtraction SPECT, generating a diagnostic value based on combined ictal and interictal values that is greater qualitatively than either alone.

**REFERENCES**


