Despite the new advancements in antiepileptic drug development, thousands of people with epilepsy will remain intractable to medication. For a considerable proportion of these people, epilepsy surgery is a consideration for better control of their seizures. Resective surgery is now standard practice for patients with medication-refractory epilepsy. Temporal lobectomy continues to be the most common surgery performed. Once patients fail 2 to 3 optimal trials of antiepileptic medication, further drug therapy offers a minimal number of patients freedom from seizures. In contrast, temporal lobectomy in carefully selected patients may result in seizure-free outcomes in more than 70% to 90% of patients with intractable seizures. As technology and drug availability increases in the new millennium, it is important for the primary care physician to be aware of epilepsy surgery as a means to treat patients with antiepileptic drug–refractory epilepsy.

Of 150,000 people who develop epilepsy each year, 20% have seizures that are medically intractable. At a population level, epilepsy that is manifest by complex partial seizures is the most frequently occurring single seizure type and comprises up to 55% of adult seizures with a cumulative incidence of 3% by age 75 years. Temporal lobe epilepsy is common, with large surgical centers reporting 70% to 85% of complex partial seizures originating in the temporal lobes. Patients with temporal lobe epilepsy may be remarkably resistant to treatment with antiepileptic drugs. Complex partial seizures demonstrate impairment of consciousness, automatisms, and focal epileptiform discharges on electroencephalogram (EEG) recordings. Poorly controlled seizures may result in treatment with 2 or more antiepileptic drugs, clinical toxic effects, continued seizures, and subsequent deterioration of educational, psychosocial, and cognitive skills. With the frequency of temporal lobe–complex partial seizures, it is of no surprise that the temporal lobes are the most common target in epilepsy surgery. Surgery performed after medical intractability may limit the deterioration in quality of life.

SURGICAL CANDIDACY

When medical management has failed, surgery should be considered. There are several caveats that favor surgical referral. First, the seizures are disabling and intractable to high therapeutic levels of first-line antiepileptic drugs. Second, if resective surgery is considered, a well-defined epileptogenic zone must be localized. Additionally, the epileptogenic zone must be surgically accessible and in a functionally silent cortex.

MEDICAL INTRACTABILITY

Before surgery is considered, a patient must meet the basic premise of medical intractability.
therapy may be superior to polypharmacologic use. Aggressive monotherapy (ie, rash) that prevents efficacy or idiosyncratic reactions (ie, rash) that prevent efficacy. This is highly individualized. Medial intractability is not only seizure persistence to maximal tolerated antiepileptic drug doses, but includes adverse effects or idiosyncratic reactions (ie, rash) that prevent efficacious use. Aggressive monotherapy may be superior to polypharmacy in some patients. Improved seizure control, better tolerability, reduced drug interaction and expense, and better compliance are benefits of monotherapy.

When considering neurosurgical intervention for intractable epilepsy, it is important to understand that social disability and the effect of the patient seizure type(s) are unique to each individual. Some patients may be medically intractable but well compensated, while others, owing to physical, mental, or emotional ramifications, may derive only marginal overall benefit. Patients with refractory, disabling, complex partial seizures of a single and stereotyped behavior and a unilateral temporal epileptiform discharge noted on EEG readings are the best candidates for surgery. The patients who should be deferred for epilepsy surgery early in the course of treatment are those in whom there is a lesion identified on neuroimaging studies. Psychosis or serious psychiatric problems are a relative contraindication. Likewise, patients with limited support at home, or for whom control of the seizures will make little difference are probably less appropriate candidates for surgery. Severely retarded individuals, those with only minor motor seizures or simple partial seizures, or those with difficulty cooperating throughout the presurgical process are limited candidates for resective surgery.

PRESURGICAL EVALUATION

The goal of the presurgical evaluation is to characterize the seizure type(s) and ascertain from where they originate in the brain to best determine the precise neurosurgical approach to treatment. When hemispherectomy is considered, presurgical evaluation needs to identify the hemisphere involved. If the epileptogenic zone seems to be multifocal or so diffuse, vagus nerve stimulation or section of the corpus callosum to inhibit seizures or their spread may help limit seizures and their consequences. The presurgical evaluation in these situations need only exclude focal excision as a treatment. For focal excision, localization and localization of the epileptogenic zone must be known. In addition, the extent and relationship of the functional cortex surrounding the region being considered for ablation must be known.

MAGNETIC RESONANCE IMAGING

Magnetic resonance imaging (MRI) of brain anatomy is the most important imaging technique used during preoperative evaluation. The principal role is to anatomically localize the epileptogenic zone. Regarding partial epilepsy, MRI is clearly superior to computed tomography scanning in the detection of structural lesions. High-resolution techniques and specialized sequences augment routine imaging with MRI. Using thin-section coronal images and special sequences that include fluid-attenuated inversion recovery sequences, mesial temporal focal pathological features are more distinct. Gadolinium-diethylenetriamine pentaacetic acid does not enhance detection of small lesions in patients with epilepsy and should be used only when a mass lesion or breakdown of the blood-brain barrier is present. Magnetic resonance imaging has an overall sensitivity of 86% compared with the simple use of surgical pathologic findings.

Magnetic resonance spectroscopy is a neuroimaging technique that uses the same instruments as MRI but incorporates specially designed software to noninvasively measure the chemical components of the tissue that has been imaged. Its role is to develop a chemical spectra that is displayed on film media to measure in vivo cellular metabolism. Magnetic resonance spectroscopy can reliably lateralize and detect neuronal loss and glial proliferation in intractable temporal lobe epilepsy. Proton magnetic resonance spectroscopy measures N-acetylaspartate, which reflects neuronal activity and lateralizes subtle neurochemical abnormalities not noted with standard quantitative MRI. Functional MRI (fMRI) also uses the same instrument as MRI but measures rapid variations in cerebral blood flow using blood oxygenation level–dependent contrast to visualize task-specific changes in regional cerebral blood flow and metabolic function. Functional MRI has been shown to remain in agreement with the Wada test in correctly lateralizing language function. Detecting asymmetries in memory activation can also be shown using fMRI. Together, the successful lateralization of language and memory promises fMRI to become a noninvasive alternative to the Wada test.

FUNCTIONAL NEUROIMAGING

While various functional imaging modalities have been used in the
study of partial epilepsy, positron emission tomography (PET) using fluorodeoxyglucose has assumed the bulk of use. With PET scanning, unilateral hypometabolism, usually in the temporal lobe, is found in 70% to 80% of patients with complex partial seizures.25 Scans using PET during the seizures (ictal) have not been as accurate owing to the imaging of regions of seizure propagation, as well as the altered peri-ictal metabolic patterns imaged. Single-photon emission computed tomography (SPECT) to measure regional cerebral blood flow or receptor binding is more readily available and features a reproducible and reliable localizing capability. While focal interictal hypoperfusion is unreliable, ictal SPECT correlates very well with seizure onset, making this technique a more practical approach than PET.26,27

**VIDEO EEG MONITORING**

**Seizure Behavior**

Closed-circuit television with videotaping and simultaneous EEG recording allows the documentation, storage, and review of the seizures. Recording 3 or more seizures is the standard practice in some centers during presurgical evaluation. Video EEG monitoring for 3 to 7 days may be necessary. The characteristics of the aura and seizure behavior (semiology) of partial seizures help to localize brain regions of seizure origin. The hemispheric lateralization or lobar localization value of auras, motor patterns, or automatisms suggest the site of the seizure’s origin or later propagation.28 Useful lateralizing features include unilateral clonic activity, dystonic posturing, or tonic posturing, and these findings denote a contralateral seizure origin in most patients. Speech during a seizure suggests a focus contralateral to the language-dominant hemisphere. Unilateral automatisms suggest ipsilateral seizure onset. Sustained forced head rotation for longer than 10 seconds prior to secondarily generalized tonicoclonic seizures is a highly reliable sign for seizure onset contralateral to the seizure focus.

**Scalp EEG Recording**

Electroencephalogram monitoring with recording electrodes attached to the scalp is performed initially to obtain interictal (between seizures) and ictal (during seizures) information regarding seizure onset. Scalp-based monitoring using extracranial electrodes is essential to verify that the seizures are indeed epileptic and to help localize the zone of seizure onset. Because many epileptic foci lie in the medial temporal, basal temporal, or basal frontal areas distant from the scalp, special electrodes may provide additional useful data. Sphenoidal electrodes are commonly used given their inferior frontotemporal position subserved, suitability for long-term EEG monitoring, and less tendency for artifact (as compared with nasopharyngeal electrodes). Electroencephalogram morphological activity during seizures is variable, can begin after clinical onset, and may be obscured by artifact. Most patients with temporal lobe seizures have anterior temporal interictal spikes.29 While the reliability of using scalp EEG monitoring for ictal localization has been questioned, one study30 comparing scalp EEG monitoring and depth electrodes on intracranial recording found that unilateral temporal and sphenoidal ictal patterns were strictly defined and correctly predicted findings from the depth recordings in 82% to 94% of cases. Scalp and sphenoidal recordings are subject to error and false lateralization on occasion and should never be used in isolation for presurgical localization. When a gross structural lesion is known to exist, it should be suspected to be the cause until proven otherwise, even when extracranial EEG evidence points to the contrary.31 Most patients with unilateral temporal lobe epilepsy have bitemporal epileptiform discharges on EEG and need not be eliminated from the surgical selection process.32 Surgery for epilepsy can be performed without implanted or intracranial electrodes if scalp EEG localization is appropriate for the video-observed clinical seizures in association with supporting evidence from neuroimaging, neuropsychological testing, and Wada testing.

**Intracranial EEG Recording**

When localization from scalp EEG is not obtained, invasive recordings may be required for definitive localization.33 Surgically implanted indwelling intracranial electrodes record EEG readings to identify the seizure focus so that resective surgery can be performed. Intracranial electrodes are commonly depth probes implanted directly into the brain parenchyma or subdural space. Grid or strip electrodes enmeshed in plastic record from the brain surface. Other arrays of electrodes include pegs, strips, and grids. Spikes are frequent and are usually multifocal in the intracranial EEG reading.34 When an intracranial EEG recording is used, analysis of the seizure recordings supplies the critical pieces of information. All types of intracranial electrodes lie closer to the anticipated generator and are implanted in an arrangement based on the noninvasive clinical workup. It is difficult to compare one electrode type with another because of the heterogeneity of individual patients. Depth and subdural strip electrodes are often used and have been used together. Comparison of bilateral depth recordings and simultaneous subdural temporal strip recordings showed that subdural strips alone may fail to localize seizure onset in some patients with seizures localized by depth EEG.35,36 Additionally, electrical brain stimulation may be performed using subdural strips or grids to help localize functional cor-
tical regions and devise a preoperative functional brain map.

**NEUROPSYCHOLOGICAL EVALUATION AND THE INTRACAROTID AMOBARBITAL PROCEDURE (WADA TEST)**

Neuropsychological evaluation is routinely performed as part of the presurgical evaluation to aid in the preoperative localization of cerebral dysfunction. A variety of selected cognitive, language, and memory tests are performed such that the results of all tests combined form a pattern that may point to the dysfunctional cortical region(s). Initial memory and language evaluations are subsequently evaluated with the Wada (intracarotid sodium amobarbital) test. This procedure involves the temporary chemical inactivation of each hemisphere by injection of amobarbital into the carotid artery, with testing of memory and language function in the “awake” hemisphere. While initially used to predict the site of language function, prediction of postoperative memory function and seizure outcome is a principal role.37

**SURGERY**

The largest group of surgical candidates comprises patients with complex partial seizures of temporal lobe origin.1 The term temporal lobectomy describes various surgical procedures directed at the temporal lobe. An en bloc anterior temporal lobectomy is a standardized operative technique at which excision of the anterior medial temporal lobe in a single block of tissue occurs. It begins with suction aspiration through the temporal horn exposing the amygdala and the anterior aspect of parahippocampal gyrus and hippocampus, which is then removed.38 Variations include resection based on intraoperative EEG, anteromedial temporal lobectomy with limited lateral resection, and more restricted removal of the amygdala and hippocampus only (amygdalohippocampectomy). Intraoperative electrocorticography records EEG readings obtained from the cortex and may define a zone of frequent interictal spiking. However, “chasing spikes” has not been convincingly shown to improve outcomes of resective epilepsy surgical procedures. Identification of the primary motor cortex using cortical stimulation or evoked potentials is preferable if localization of rolandic motor areas is needed. The most common cause of failure of temporal lobectomy is inadequate medial temporal lobe excision.39 Extratemporal epilepsies typically require more invasive recordings for definitive localization and are based on clinical and ancillary data (eg, interictal EEG abnormalities, MRI, PET).

**HEMISPHERECTOMY**

In children with congenital or postencephalitic hemiplegia, hemispherectomy usually dramatically arrests focal motor and generalized convulsive seizures. Total anatomic hemispherectomy has given rise to functional hemispherectomy, which is anatomically incomplete but physiologically complete with the removal of the central and temporal portion of the hemisphere and severing of all commissural projections connecting the hemisphere.40

**CORPUS CALLOSAL SECTION**

Corpus callosotomy (of a partial or complete section of the corpus callosum) is often a palliative form of epilepsy surgery. Recurrent seizure-related injury and morbidity related to generalized tonic or atonic seizures (drop attacks) respond best.41 Corpus callosal section to limit seizure injury may be helpful in patients for whom resective surgery is inappropriate (multifocal or widespread epileptogenicity) or impractical owing to severe mental dysfunction.

**VAGUS NERVE STIMULATION**

Vagus nerve stimulation is an alternative to brain surgery. It uses a nonpharmacologic, surgically implanted device for patients with drug-resistant seizures via intermittent electrical stimulation of the left vagus nerve. Vagus nerve stimulation involves the surgical placement of a generator (similar to a cardiac pacemaker) in the chest with electrodes connected subcutaneously to the vagus nerve in the neck. Intermittent electrical stimulation occurs at preprogrammed cycle rates. Settings involving current, frequency, and duration of stimulation are regulated by a computer. Standard stimulus settings for an electrical current that is delivered for 30 seconds every 5 minutes may be adjusted. Approximately 30% to 40% of patients experienced a 50% seizure reduction.42,43 As with corpus callosotomy, a relatively limited number of patients are rendered seizure free. Though approved for use in patients older than 12 years, efficacy in children and patients with symptomatic generalized epilepsy seems particularly promising. Hoarseness, throat pain, coughing, and tingling at the electrode site are potential adverse effects experienced during the time of stimulation. No cardiac or pulmonary residual effects have been noted.42,44 Unlike antiepileptic drugs, systemic and idiosyncratic adverse effects have not been noted. A favorable attribute is 100% compliance and the potential for concomitant drug reduction.45

**OUTCOME**

Patients with temporal lobectomy, extratemporal resection, hemispherectomy, corpus callosotomy, or vagus nerve stimulation have different pathologic mechanisms, surgical approaches, complications, and outcomes. A 4-level outcome classification for resective surgery has been
proposed by Engel: class 1, seizure-free with or without auras; class 2, rare seizures (“almost seizure free”); class 3, worthwhile postoperative improvement (>90% reduction from preoperative frequency); and class 4, no worthwhile improvement. Several large published series have documented seizure outcomes with 70% to 90% seizure-free rates, with prolonged efficacy seen at 5-years’ follow-up. Patients with temporal lobe epilepsy as well as certain subgroups such as those with structural lesions typically have higher seizure-free rates. Limiting the deleterious effects of seizures on educational, social, behavioral, and cognitive functioning early on in the course of refractory epilepsy, may result in marked gains in pediatric epilepsy surgery.

COMPLICATIONS

The mortality rate following temporal lobe resection is less than 1%. Visual field defects are not uncommon following temporal lobectomy; however, patients rarely notice visual dysfunction. Up to 30% may experience mild naming and verbal problems as a result of surgery in the language-dominant hemisphere, with fewer than 2% of patients encountering permanent or denser speech difficulties. Hemiparesis seen in 5% of older series has been reported in fewer patients recently. Patients with good postoperative seizure control have had improvement in full-scale IQ tests regardless of the side of the brain on which surgery is performed, whereas those with poorly controlled seizures incurred little change or mild losses. Several variables modulate the frequency and severity of memory deficits. Favorable seizure control, nature and extent of resection, dominance, and baseline function or dysfunction all affect individual outcome.

Hemispherectomy previously performed with complete anatomical hemispheric evacuation yielded major morbidity and mortality in patients and has been significantly reduced using a “functional” approach to incompletely remove an entire hemisphere. While complications of infection, hemorrhage, and hydrocephalus can occur, these potential complications are affected based on the volume involved in resection. Complications of corpus callosal section have included transient left-sided neglect, apraxia, mutism or stuttering, cerebral infarction, hemorrhage, or infrequently, death.

In conclusion, epilepsy surgery should be considered for certain patients with complex partial seizures that are poorly controlled by antiepileptic drugs. While the development of new antiepileptic drugs to appear in the new millennium brings the hope of new and improved efficacy and tolerability, the number of patients with intractable seizures will remain high. For certain patients, resective surgical procedures for temporal lobe epilepsy, epilepsy with a lesion on neuroimaging studies, and hemispherectomy are subpopulations of patients for whom surgery is an early consideration. A team approach to the neurosurgical treatment of epilepsy is essential. An understanding of the surgical evaluation and a close working relationship with the primary care physician as part of the epilepsy surgery team is crucial for cohesive and successful management of epilepsy.

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