Moyamoya Disease: New Approaches in Arizona

Moyamoya disease is a rare disorder characterized by luminal stenosis secondary to intimal thickening and smooth muscle cell proliferation of the distal internal carotid arteries and the main branches of the circle of Willis. An aberrant, compensatory network of blood vessels develops to maintain collateral circulation to brain tissue. This pathophysiologic process leads to a characteristic “puff of smoke” appearance on angiographic studies (Figure).

Although moyamoya disease occurs in people of all ages, it typically affects children and adults under the age of 50. It can be difficult to diagnose and can cause recurring transient ischemic attacks (TIAs), strokes, seizures and cognitive deterioration.

As a center of expertise for cerebral microvascular surgery, Mayo Clinic has a distinguished history of treating moyamoya disease. Neurosurgeons at Mayo Clinic in Phoenix/Scottsdale, Arizona, are pioneering new approaches to treatment, to improve cerebral perfusion with the goal of eliminating or reducing complications of the disease.

While moyamoya disease is rare overall, it’s probably underdiagnosed,“ says Bernard R. Bendok, M.D., chair of Neurosurgery at Mayo Clinic’s campus in Arizona. “It’s an important cause of stroke in young people. Because of the associated complications, the impact per case is high.”

Diagnosis of moyamoya disease requires an angiogram, which is not always routinely performed after stroke or TIA. However, MRI and CT, which are generally done after stroke or TIA, can provide subtle signs of moyamoya disease, indicating the need for an angiogram.

Dr. Bendok, who has treated moyamoya disease for 20 years, notes that narrowing of the carotid arteries shown on MRI and CT might be assumed to indicate atherosclerosis.”But it could be moyamoya disease,” he says. “In atherosclerosis, the narrowing of the carotids tends to be irregular, whereas it’s typically smoother in moyamoya disease and, more often than not, bilateral.”

Improving perfusion

At Mayo Clinic, perfusion studies are performed before treatment for moyamoya disease to obtain an objective endpoint for improving vascularization. In addition, cognitive testing and quality-of-life measurement are done before and after treatment.

Treatment of moyamoya disease generally focuses on preventing stroke. “However, stroke prevention is just the tip of the iceberg,”Dr. Bendok says. “Preventing hemorrhage is an important consideration, and managing associated aneurysms surgically or with endovascular treatments could be another issue. It’s also critical to pay attention to the fact that hypoperfusion can reduce cognitive abilities, and improved perfusion can reverse that decline.”

The preferred surgical approach to treatment of moyamoya disease — direct or indirect bypass — has been controversial. “Our approach is always to do an indirect bypass. We often add a direct bypass if the anatomy is favorable, especially when the patient has progressive symptoms related to hypoperfusion.”

Typically, revascularization treatment

Figure. Angiogram of the aberrant network of blood vessels in a patient with moyamoya disease shows the characteristic “puff of smoke” appearance.
Electromyography (EMG) is an essential tool for the diagnosis of patients with neuromuscular disorders. When performed with the required rigor, EMG provides objective measures to complement clinical assessment of patients with complex conditions — information that is critical to confirming or ruling out neuromuscular disorders as well as monitoring progress during treatment.

All three Mayo Clinic campuses have board-certified electrophysiologists and technicians who test patients referred directly for EMG testing from other centers as well as Mayo Clinic patients. In addition to nerve conduction studies and needle examination of common and uncommon nerves and muscles, Mayo Clinic offers specialized tests such as diaphragmatic and peripheral nerve ultrasound, and single fiber EMG.

“Our focus on patient care and attention to detail allow us to provide the highest quality of EMG testing,” says Ruple S. Laughlin, M.D., a consultant in Neurology and medical director of the EMG laboratory at Mayo Clinic in Rochester, Minnesota. “The interpretation of needle data can be subjective. We bring finesse and expertise to that interpretation, in addition to technical rigor with testing.”

The physicians in the EMG labs at Mayo’s three campuses take time and care to focus on every patient’s clinical findings as they consider an individual EMG testing plan for each patient. “EMG serves as an extension of the clinical exam,” Dr. Laughlin notes. “It can provide more nuance about the location of the problem within the neuraxis, the severity of the condition and even the prognosis for recovery.”

“A physician can refer patients to any of our three campuses and know that each EMG lab will use the same protocols, approaches and equipment. We really consider ourselves one lab at three different sites,” adds Devon I. Rubin, M.D., a consultant in Neurology and medical director of the EMG laboratory at Mayo Clinic in Jacksonville, Florida.

Specialized testing
Mayo Clinic has a rich history of innovation in EMG, such as the development and enhancement of nerve conduction study techniques and description of a new type of unusual iterative discharge during needle EMG (Figure 1). As a major academic center with referrals from tertiary institutions, Mayo Clinic has the resources to provide a full range of electrophysiological testing for patients with all types of common and rare neuromuscular disorders, such as neuropathies related to diabetes, chemotherapy, autoimmune neuromuscular diseases, compression, spine-related conditions, and neuromuscular junction diseases such as myasthenia gravis.

Awake surgery
To avoid complications during revascularization, Dr. Bendok and colleagues have introduced awake surgery for treatment of moyamoya disease and other cerebral vascular conditions. “Awake surgery is the best form of neuromonitoring,” Dr. Bendok says. “If the patient experiences a symptom during surgery, we can quickly increase the patient’s blood pressure.”

Patients are kept hypertensive during neurovascular awake surgery procedures, and contralateral motor movements are periodically evaluated. No episodes of significant blood pressure fluctuations have occurred and no adverse events have been noted. The postoperative course for the patients has been uneventful, without new or worsening deficits.

Dr. Bendok’s commitment to improving perfusion began early in his career when he treated a young woman with moyamoya disease. She was nearly unresponsive at presentation due to poor brain perfusion. Sometime later, after giving a talk on moyamoya disease at a hospital, Dr. Bendok was approached by an audience member — his former patient, who was working in the hospital’s coding and billing department.

“After her treatment she was able to earn an associate degree,” Dr. Bendok says. “That experience was a powerful demonstration to me of the fact that you can help people by improving brain perfusion.”

EMG: Innovation and Quality Nationwide
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Figure 1. Electromyography (EMG) shows an unusual waveform, indicating an iterative discharge identified by Mayo Clinic neurophysiologists and termed motor unit potential induced repetitive discharge (MIRD). MIRDs aren’t evoked by an external stimulus but rather are fired semirhythmically with muscle activation and ceased with relaxation, confirming initiation by a voluntary motor unit potential.

Bernard R. Bendok, M.D.

Ruple S. Laughlin, M.D.
Lambert-Eaton myasthenic syndrome and congenital myasthenic syndromes.

“We’re able to analyze any nerve or muscle problem in detail, including those that require specialized tests,” says Mark A. Ross, M.D., a consultant in Neurology and medical director of the EMG laboratory at Mayo Clinic in Phoenix/Scottsdale, Arizona.

In addition to routine needle EMG and nerve conduction studies, Mayo Clinic performs:

- Diaphragmatic ultrasound (Figure 2) to determine if a neuromuscular problem is causing respiratory weakness
- Ultrasound of the hand to identify carpal tunnel syndrome
- Single fiber EMG, the most sensitive test to confirm or refute a diagnosis of myasthenia gravis
- Cranial nerve testing, to identify nerve root injury or irritation
- Laryngeal EMG, for patients with voice abnormalities or other voice disorders
- Prolonged exercise testing, to detect problems with nerve channels along muscle fibers in patients with episodic weakness
- Cramp-fasciculation testing, to detect peripheral nerve hyperexcitability

Among nonroutine EMG tests, diaphragmatic ultrasound is relatively new but used increasingly at Mayo Clinic. Dr. Ross cites the case of a patient with amyotrophic lateral sclerosis who wanted to enroll in a clinical trial of a diaphragm-pacing system. However, participants in the trial were required to have phrenic nerve responses — which typical nerve conduction studies hadn’t detected on one of the patient’s sides. Dr. Ross suggested diaphragmatic ultrasound.

“The ultrasound demonstrated that the diaphragm was actually moving quite normally on that side,” he says. “So we looked at the phrenic nerve studies again and in fact were able to get a response. That made a big difference for this patient because he was able to join the study.”

Ultrasound is also increasingly used to assess compression for median neuropathies or other peripheral nerve lesions. To enhance patients’ convenience, Mayo Clinic is initiating point-of-care ultrasound for people with suspected carpal tunnel syndrome. Typically, these patients might have nerve conduction studies and then consult a hand surgeon. To determine eligibility for surgery, the surgeon might recommend ultrasound, which can detect anatomical compression.

“We’re streamlining that process,” Dr. Laughlin says. “If patients present for carpal tunnel, we can do a focused ultrasound then and there, and provide the additional information to the hand surgeon. That saves the patient a visit and allows the hand surgeon to move forward with treatment.”

Partnering for patient care

At Mayo Clinic, EMG technicians are overseen directly by neurophysiologists. Teams of physicians and technicians work together daily, fostering trust and a commitment to quality and patient care.

“Everyone working in the lab has a goal of continuing Mayo’s tradition of excellence in EMG and providing the absolute best care for every patient every day,” Dr. Rubin says. “We understand that we are seeing patients with very complex disorders whose diagnoses might still be unclear. Our common goal is to ensure exceptional quality in our testing so that we can come to an accurate diagnosis.”

Posterior Fossa Parenchymal Biopsy: Yield and Safety

The diagnosis of inflammatory brain diseases often requires a tissue diagnosis. Neuroinflammatory diseases such as neurosarcoidosis and chronic lymphocytic inflammation with pontine perivascular enhancement responsive to steroids (CLIPPERS) can be difficult to differentiate from neoplastic or infectious conditions on clinical or radiologic grounds alone. Although hemispheric biopsy is commonly performed, the yield and safety of posterior fossa biopsies haven’t been clearly defined.

At Mayo Clinic in Rochester, Minnesota, cerebellar and brainstem parenchymal biopsy for diagnosis of tumor and inflammatory conditions is performed in carefully selected patients (Figure). The diagnostic yield and safety of the procedures at Mayo Clinic are similar to yield and safety of hemispheric biopsy.

“Physicians typically shy away from performing biopsies in the eloquent area of the posterior fossa, particularly the brainstem. The risk of complications is thought to be high, and there is...
the possibility of death if bleeding occurs within the confined space available. But that’s not what we’ve found at Mayo Clinic,” says W. Oliver Tobin, M.B., B.Ch., BAO, Ph.D., a consultant in Neurology at Mayo Clinic’s campus in Minnesota. “In carefully selected patients, it is appropriate to biopsy.”

A study of posterior fossa biopsies performed at Mayo Clinic from 1996 to 2009 found that the diagnostic yield in patients with diverse pathologies was 80 percent. Transient complications were seen in 11 percent of cases. Only three patients sustained permanent, nonfatal complications; two deaths were attributable to biopsy. The study, published in the December 2015 issue of World Neurosurgery, reviewed 137 posterior fossa biopsies performed in 136 patients.

“These biopsies actually look pretty safe,” Dr. Tobin says. “That’s attributable to our careful selection of patients for this procedure. But we also believe that the level of experience our neurosurgeons have with this procedure is improving our outcomes.”

Fredric B. Meyer, M.D., enterprise chair of Neurosurgery at Mayo Clinic, performs these biopsies. “Coming to a place like Mayo Clinic is important when patients are suffering from neurological deterioration and no answer has been identified,” he says. “There’s a chance that we can get an answer and, we hope, find a treatable disease.”

“This is a team endeavor,” he adds. “The neurologist is key in conducting exhaustive evaluations to make sure a diagnosis can’t be provided without undertaking this type of biopsy. It’s also important to have good neuroradiology, so you can be sure you’ve identified everything before the procedure. Then you need an expert pathologist who can look at small bits of tissue and figure out what’s going on. That’s an art and a science.”

Definitive diagnosis

Mayo Clinic neurologists see many patients with posterior fossa conditions, due to the center’s expertise in neoplastic and inflammatory brain-stem lesions as well as in atypical demyelinating conditions. Patients referred to Mayo Clinic with these conditions often have not responded to immunotherapy and other treatments.

“In these cases the clinical scenario is clouded by the fact that the patients may have been on treatment. It can be challenging to get an accurate diagnosis without biopsy,” Dr. Tobin says.

Among patients with suspected posterior fossa neoplasm who undergo biopsy, about 85 percent have neoplasm confirmed by the procedure. “That’s 15 percent who don’t, and that is very useful clinical information,” Dr. Tobin says.

Among patients with suspected neuroinflammatory disease who undergo biopsy, about 45 percent receive a definitive tissue diagnosis. “Additionally, we’re able to confirm, for most of the additional patients in that group, that they don’t have cancer,” Dr. Tobin says. “That allows us to treat the condition with more confidence, either with immunotherapy or clinical monitoring.”

Among patients referred with suspected CLIPPERS — an atypical demyelinating condition identified at Mayo Clinic in 2010 — about half are diagnosed with the disease. “In patients with suspected CLIPPERS, brain biopsy should be considered if at all possible because we don’t have a specific biomarker for that disease as yet,” Dr. Tobin says. “CLIPPERS can be misdiagnosed as tumor, lymphoma, vasculitis or sarcoidosis, which requires different treatment paradigms.”
Patients with widespread systemic malignancy and other significant comorbidities are generally poor candidates for posterior fossa biopsy. However, patients with suspected focal lesion or neuroinflammatory disease — even patients experiencing severe symptoms such as dysarthria, ataxia and swallowing problems — can often tolerate posterior fossa biopsy well.

“At Mayo Clinic we have a large number of providers with expertise in neuro-oncology and in inflammatory brainstem disorders,” Dr. Tobin says. “As a result, we have a large volume of patients with unusual presentations, who may benefit from a posterior fossa brain biopsy. That experience helps us provide the best possible outcome for patients.”

For more information


Intraneural Perineuriomas: Common Cause Identified

Intraneural perineuriomas are benign peripheral nerve sheath tumors that cause progressive and debilitating focal extremity weakness. They occur most commonly in young patients, and no therapeutic options exist. The etiology of these tumors, which don’t metastasize outside peripheral nerves, has remained largely unknown.

Researchers at Mayo Clinic in Rochester, Minnesota, have identified a common cause for intraneural perineuriomas and an unexpected shared pathogenesis with intracranial meningiomas. As described in the February 2017 issue of Annals of Neurology, the researchers discovered three novel recurrent mutations in the WD40 domain of the TRAF7 protein (Figure 1). TRAF7 mutations also frequently occur as a genetic cause of meningioma, the most common primary brain tumor.

“The fact that meningiomas and perineuriomas share the same mutation supports a hypothesis that both tumors originate from the same cell. The meninges are probably embryologically related to the lining of nerve fascicles,” says Christopher J. Klein, M.D., a consultant in Neurology at Mayo Clinic’s campus in Minnesota. “That is a true neuroscience breakthrough.”

The discovery also indicates a pathway for potential treatments. “Understanding the pathogenesis of these tumors is critical to finding novel therapies,” says Michelle L. Mauermann, M.D., a consultant in Neurology at Mayo Clinic’s campus in Minnesota. “Intraneural perineuriomas can’t be resected because they are entwined in the nerve. For patients, at this time, we use rehabilitation and bracing to try to preserve function, and consider tendon transfers when weakness progresses.”

Rare and debilitating
Intraneural perineuriomas can be overlooked or mistaken for other conditions. “They are quite rare, so most neurologists and neurosurgeons will never see a case or, if they do, may not recognize it,” Dr. Mauermann says.

Patients with intraneural perineuriomas might be diagnosed with other nerve sheath tumors, such as paraneoplastic sensory neuronopathies. “These tumors are often treated for symptoms, and the role of biopsy is often not appreciated,” says Dr. Mauermann.

Figure 1. A-C. Typical histology and gene discovery in intraneural perineurioma. Illustrative case (A) epoxy section at similar level and magnification as shown in paraffin preparations with pseudo-onion bulb formations around occasionally seen thin myelinated fibers with (B) Schwann cell preparation (S-100) demonstrating sparse reactivity of the Schwann cells at the center and (C) prominent epithelial membrane antigen (EMA)-reactive staining of the leaflets of the pseudo-onion bulbs. D. Functional domains and location of recurrent TRAF7 mutations. The WD40 domain is the region with identified mutations in meningiomas. E. Rainbow cartoon representation of a model of TRAF7 WD40 domain structure. The three residues mutated in intraneural perineuriomas are highlighted as gray spheres and cluster together on the protein predicted to interfere with TRAF7 interaction with other proteins and/or to cause instability of the WD40 domain. F. TRAF7 immunoreactivity in perineurioma occurs in the same areas that reacted to EMA. Image reprinted with permission from Annals of Neurology.
as neurofibromas, schwannomas or malignancies — resulting in resection or repeated biopsies that further damage patients’ nerves. Rarely, patients are diagnosed with autoimmune problems and given unnecessary immunotherapy. In very young patients, weakness might be attributed to birth trauma or a perinatal stroke.

Although the tumors are most common in childhood and early adulthood, Mayo Clinic neurologists have seen patients with disease onset occurring after age 50. Insidious, gradual onset of progressive mononeuropathy is typical; areas of nerves, such as the brachial plexus or lumbosacral plexus, are sometimes involved.

The sciatic nerve is the most common tumor site (Figure 2). “Most patients have a foot drop, which requires them to wear an ankle foot orthosis that limits their ability to be active,” Dr. Mauermann says. Patients might also have radial nerve involvement, resulting in wrist drop or finger drop that limits hand function.

“It often takes years for the patient to recognize the weakness. But it can progress to the point where it causes atrophy and disability,” Dr. Mauermann says. “There is often sensory involvement, but it’s overshadowed by the motor issues. This significantly affects the life of an active young person.”

Serendipity and hard work
The identification of TRAF7 mutations in patients with intraneural perineuriomas required advances in technology and expertise from multiple Mayo Clinic specialists. As a major clinical, research and academic center, Mayo Clinic has the resources for this complex work.

Mayo Clinic radiologists and medical physicists worked together to develop novel 3-tesla MRI imaging techniques for imaging patients with suspected perineurioma. This led to elucidation of the condition’s typical radiologic features. “Because of this we have been able to identify lesions that may have been overlooked in the past,” Dr. Mauermann says.

Previous studies had linked intraneural perineuriomas to chromosome 22 mutations. Initially, the Mayo Clinic researchers used fluorescence in situ hybridization (FISH) to investigate that linkage. “But FISH just didn’t have the sensitivity we needed,” Dr. Klein says.

Eventually, the researchers were able to use whole-exome sequencing, a newly determined copy number algorithm developed at Mayo Clinic, and high-resolution whole-genome microarray. Those studies revealed large abnormalities in multiple chromosomes, including chromosome 22, in two of the 16 tumor cases studied. However, 10 of the 16 tumor cases (62.5 percent) had the TRAF7 mutations.

“Whole-exome sequencing allows us to see as few as 10 base-pair deletions. As a result, we found that the majority of these tumors are caused not by a large deletion but by a point mutation,” Dr. Klein says. “We never expected that. It was serendipity and the result of a lot of hard work.”

TRAF7 ubiquitinates the tumor-suppressing p53 protein. Dr. Klein suggests that TRAF7 mutations may result in abnormal p53 lingering in nerves. “That might explain the formation of benign tumors,” he says. “The tumor exists because p53 is a little abnormal, but the tumor is benign because p53 remains present.”

As a circulating protein, p53 might also provide an avenue for treatment. “If we could modify a protein circulating through the blood vessels of the nerves, then we might have a meaningful therapy,” Dr. Klein says.

The seeds of Mayo Clinic’s identification of a cause for intraneural perineuriomas were planted decades ago, when Peter J. Dyck, M.D., a consultant in Neurology at Mayo Clinic’s campus in Minnesota, created a frozen nerve tissue bank. Samples from that tissue bank were used in the genomics study.

“Dr. Dyck had the vision to save a tiny portion of every nerve tissue biopsy under liquid nitrogen for research,” Dr. Klein says. “Without this precious material we would not have been able to do this study.”

“Mayo Clinic is unique. We bring to this work expertise in the neurosciences and radiology, the skill of neurosurgeons who can biopsy these tumors, and a strong patient base,” Dr. Mauermann adds. “People here are driven to push the science forward.”

For more information

Research Highlights in Neurology and Neurosurgery

Genetic Screening for Alzheimer's in African-Americans
Alzheimer's disease (AD) is understudied in African-Americans, despite the fact that the disease is twice as prevalent in African-Americans as in Caucasians and other ethnic groups. Mayo Clinic researchers in Jacksonville, Florida, have found a new gene mutation that may be a risk factor for late-onset AD in African-Americans. The discovery results from the first comprehensive genetic screening in African-Americans for potentially pathogenic variants in known Alzheimer's genes. The researchers focused on the APP, PSEN1 and PSEN2 genes, which are known to contribute to early-onset AD. They sequenced the genome of 238 African-American study participants: 131 with late-onset AD and 107 control participants. Six variants within the three genes were found in the Alzheimer’s patients but not in the control participants. The researchers then looked for these gene variants in a second group of 300 African-American participants: 67 with late-onset AD and 233 control participants. Four of the gene variants were present in the control group. However, two variants — one in a shorter form of PSEN1 and one in PSEN2 — were not present in the control group, indicating that they may pose a risk for late-onset Alzheimer’s disease in African-Americans. Although PSEN1 variants had previously been found in African-Americans with AD, the discovery of a likely pathogenic PSEN2 gene variant is new in this population. The researchers note that the PSEN2 variant may be unique to the African-American population, as it hasn’t been found in Caucasians with AD or in gene repositories from more than 60,000 subjects who aren’t African-American. (N’Songo A, et al. Comprehensive screening for disease risk variants in early-onset Alzheimer’s disease genes in African Americans identifies novel PSEN variants. Journal of Alzheimer’s Disease. 2017;56:1215.)

Mental Activities After Age 70 May Help Prevent MCI
Cross-sectional associations between engagement in mentally stimulating activities and decreased odds of having mild cognitive impairment (MCI) or Alzheimer’s disease (AD) have been reported. However, little is known about the longitudinal outcome of incident MCI as predicted by mentally stimulating activities in old age. Researchers at Mayo Clinic in Phoenix/Scottsdale, Arizona, have found that cognitively normal people ages 70 and older who engaged in mentally stimulating activities had a decreased risk of developing MCI. The researchers followed 1,929 cognitively normal participants in the population-based Mayo Clinic Study of Aging for an average of four years. The median age of study participants at baseline was 77 years. At baseline, participants provided information about mentally stimulating activities within one year before enrollment in the study. Neurocognitive assessment was conducted at baseline, with evaluations at 15-month intervals. After adjusting for sex, age and educational level, the researchers found that the risk of new-onset MCI decreased by 30 percent with computer use, 28 percent with craft activities, 23 percent with social activities and 22 percent with playing games. Participants who performed these activities at least once or twice a week had less cognitive decline than those who did so only two to three times a month or less. The benefits of cognitive engagement were seen even among carriers of apolipoprotein E (APOE) ε4, a known genetic risk factor for MCI and AD. However, among APOE ε4 carriers, only computer use and social activities were associated with a decreased risk of MCI. (Krell-Roesch J, et al. Association between engagement in mentally stimulating activities and decreased odds of having incident mild cognitive impairment, with an analysis of the APOE ε4 genotype. JAMA Neurology. 2017;74:332.)

Autonomic Changes in Children With Temporal Lobe Seizures
Symptoms and signs of autonomic dysfunction are commonly noted in seizures of temporal lobe onset. In particular, ictal tachycardia and ictal hypoxemia have been considered possibly important in the pathophysiology of sudden unexplained death in epilepsy. Researchers at Mayo Clinic in Rochester, Minnesota, have determined that peri-ictal autonomic changes are frequent among pediatric patients with temporal lobe seizures but seldom require intervention. The researchers evaluated the prevalence and risk factors for these autonomic changes in temporal lobe-onset seizures in children assessed at Mayo Clinic’s epilepsy monitoring unit between June 1, 2009, and Oct. 31, 2013. Forty-nine children were identified. Overall, peri-ictal autonomic changes were observed in 32 (66 percent) of the patients and 91 (53 percent) of 172 evaluated seizures. Tachycardia (51 percent), oxygen desaturation (33 percent) and salivation (27 percent) were the most frequent autonomic changes identified. The researchers note that larger population-based studies are needed to further explore the potential link of temporal lobe seizures causing autonomic dysfunction. (Whealy M, et al. Prevalence and risk factors of peri-ictal autonomic changes in children with temporal lobe seizures. Pediatric Neurology. 2017;67:36.)

To read more about Mayo Clinic neurosciences research and patient care, visit http://www.mayoclinic.org /medical-professionals.
Expedited Patient Referrals to Mayo Clinic
Departments of Neurology and Neurologic Surgery

While Mayo Clinic welcomes appointment requests for all neurologic and neurosurgical conditions, patients with the following conditions are offered expedited appointments:

1. Cerebral aneurysms
2. Cerebral or spinal arteriovenous malformations
3. Brain, spinal cord or peripheral nerve tumors
4. Epilepsy with indications for surgery
5. Carotid disease

Education 2017-2019 Neurology and Neurologic Surgery Continuing Medical Education Programs

2017 courses

**July**

Microvascular Surgery Skills Training — July 24-28, 2017
July 24-28, 2017
Mayo Clinic, Rochester, Minn.

Practical Clinical Neurology Update 2017
July 27-29, 2017
Caribe Hilton, San Juan, Puerto Rico

**August**

Surgical Technique for Partial Joint Denervation Workshop: Upper & Lower Extremity 2017
Aug. 24-25, 2017
Mayo Clinic, Rochester, Minn.

September

Mayo Clinic Neuroscience and Oncology Innovation Summit 2017
Sept. 7-9, 2017
Four Seasons Resort Orlando at Walt Disney World Resort, Orlando, Fla.

Mayo Clinic 9th Annual Stroke and Cerebrovascular Disease Review 2017
Sept. 14-16, 2017
The Ritz-Carlton, Amelia Island, Fla.

Mayo Clinic Sports Medicine Center Ice Hockey Summit III: Action on Concussions 2017
Sept. 28-29, 2017
Mayo Clinic, Rochester, Minn.

October

Mayo Clinic Convergence Neuroscience 2017
Oct. 24-25, 2017
The Ritz-Carlton, St. Thomas, U.S. Virgin Islands

Clinical Autonomic Quantitation Workshop 2017
Oct. 27-28, 2017
Mayo Clinic, Rochester, Minn.

November

Sleep and Stroke 2017
Nov. 4, 2017
Mayo Clinic, Rochester, Minn.

2018 courses

May

Neuro and Intensive Care: Review and Hands-on Workshops 2018
May 10-12, 2018
Loews Portofino Bay Hotel, Orlando, Fla.

2019 courses

June

8th Quadrennial International Conference on Vestibular Schwannoma and Other CPA Tumors: Advancing Care through Ideas and Innovation 2019
June 18-21, 2019
Mayo Clinic Center, Rochester, Minn.

Information and registration

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Website: www.Mayo.edu/cme/neurology-and-neurologic-surgery

Contact Us

Mayo Clinic welcomes inquiries and referrals, and a request to a specific physician is not required to refer a patient.

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