Robot-Guided Technology to Enhance Spinal Surgery

Mayo Clinic in Rochester, Minnesota, was the first center in the upper Midwest to perform spinal surgery using the latest robot-guided technology (Figure 1). The system, which incorporates advanced software to enhance surgical precision, is also available at Mayo Clinic’s campuses in Arizona and Florida.

“Our team at Mayo Clinic has performed more than 20 spinal robotic surgeries since acquiring the system in fall 2018, with positive results thus far,” says Mohamad Bydon, M.D., a neurosurgeon at Mayo Clinic’s campus in Minnesota. “Even at this early stage, it is clear that robotic technology can make spinal surgeries safer and more efficient, and result in better outcomes.”

Mayo Clinic spent almost two years studying various systems before committing to the new technology, which is currently used for surgery in the thoracic and lumbar spine. “The system can be applied to smaller, minimally invasive procedures as well as more-complex open surgeries for oncologic or spinal deformity cases,” says Matthew T. Neal, M.D., a neurosurgeon at Mayo Clinic in Phoenix/Scottsdale, Arizona.

The basis of robotic spine surgery is navigational software that was partly developed at Mayo Clinic. Mayo is collecting data from its use of the new system to further develop the technology, in conjunction with the manufacturer.

“Having a robust database from all three of our campuses will allow us to help advance this technology,” says Selby G. Chen, M.D., a neurosurgeon at Mayo Clinic in Jacksonville, Florida.

Accuracy, efficiency and safety
The new system’s major benefit is greater precision in the placement of hardware during spinal surgery. This can lead to improved outcomes and reduced complications for patients. The system is also designed to make surgeries safer and more efficient, allowing for quicker patient recovery times.

Figure 1. Mohamad Bydon, M.D., a neurosurgeon at Mayo Clinic in Rochester, Minnesota, leads a team performing spinal surgery using new robot-guided technology.

Figure 2. Postoperative X-rays show spinal hardware inserted during a robot-assisted, minimally invasive L4-S1 transformaminal lumbar interbody fusion performed at Mayo Clinic in Jacksonville, Florida. The patient was a 74-year-old man who previously underwent right-sided L4 and L5 foraminotomies for right lower extremity weakness without significant benefit. The minimally invasive fusion greatly improved his leg strength.
surgery (Figure 2). CT or fluoroscopic imaging before and during surgery help determine the path used by the robot at every level of the spine. “The system’s software guides the robotic arm into position during surgery. In that way the surgical plan is translated to trajectory guidance in the surgical field,” Dr. Bydon says. “The accuracy achieved with the system has been excellent. In addition, the disruption to tissue has been less than we would normally see. We’ve noted that patients have less postoperative pain, lower use of pain medication and shorter hospitalization.”

One of the first patients to undergo surgery with the new system had spinal instability and spondylolisthesis in addition to severe spinal stenosis. He underwent successful robotic surgery and has experienced an excellent outcome to date.

Advanced software (Figure 3) distinguishes the new system from previous technology. Mayo Clinic’s data will be used to refine the software and further improve the system.

“Currently, the robot’s primary utility is with the placement of spinal instrumentation. But as the software becomes more sophisticated, I imagine the robot will be able to assist us in other parts of the surgery, including bone work, disk preparation and potentially even deformity correction,” Dr. Chen says.

New Clue for Earlier Diagnosis of Spinal Dural AVF

Mayo Clinic has identified a unique radiographic finding that facilitates earlier diagnosis of spinal dural arteriovenous fistulas (dAVFs), paving the way to improved treatment outcomes. In the unusual MRI pattern (Figure), abrupt segments are seemingly missing amid an area of intense whole-cord contrast enhancement — a finding that Mayo Clinic calls the missing-piece sign.

“When neurologists see enhancement on spinal MRI, their automatic first thoughts are inflammation or tumor. But enhancement can be due to many other etiologies, including a fistula,” says Nicholas (Nick) L. Zalewski, M.D., a neurologist at Mayo Clinic in Rochester, Minnesota.

Spinal dAVFs are rare, with heterogenous clinical and radiologic features that can lead to misdiagnoses of inflammatory or neoplastic myelopathies. Although clinical deficits resulting from spinal dAVFs can be reversible, a delay in diagnosis is associated with severe permanent morbidity.

“Early detection and treatment are key to achieving optimal outcomes,” says Jonathan L. Carter, M.D., a neurologist at Mayo Clinic in Phoenix/Scottsdale, Arizona. “Mayo Clinic has a great deal of experience managing a variety of spinal cord disorders, which helps us to differentiate and arrive at an accurate diagnosis.”

Spinal cord angiogram, a tool critical for precisely diagnosing and locating a spinal dAVF, is performed by a designated group of neuroradiologists and neurosurgeons. “Finding the fistula is often the most difficult part. Once a spinal dAVF is correctly diagnosed, we have the ability to treat it with embolization or surgery, as needed,” says Giuseppe Lanzino, M.D., a neurosurgeon at Mayo Clinic’s campus in Minnesota. “With timely intervention, patients can have a remarkable recovery.”

Finding the missing piece

Although rare, spinal dAVFs are underdiagnosed. The initial clinical signs and symptoms can include:

- Gradually progressive myelopathy, particularly in an older patient
- Myelopathy features affecting the lower thoracic region into the conus
Deficits that suddenly worsen with exertion or Valsalva

Tortuous flow voids — another MRI finding associated with spinal dAVF — are classic but not universally present.

“It is very important to consider spinal dAVF in the differential diagnosis when evaluating patients with progressive myelopathy and abnormalities in spinal cord MRI because misdiagnosis can lead to morbidity and to unnecessary diagnostic testing and treatment,” says Iris (Vanessa) V. Marin Collazo, M.D., a neurologist at Mayo Clinic in Jacksonville, Florida. “A high index of suspicion, excellent diagnostic tools and criteria, and an experienced, multidisciplinary team are essential.”

Mayo Clinic’s extensive experience with spinal cord diseases facilitated the discovery of the spinal dAVF radiologic clue. That discovery — reported in the Dec. 1, 2018, issue of *JAMA Neurology* — arose from an earlier Mayo Clinic study that proposed diagnostic criteria for spinal cord infarction. For that large case series, published in the Jan. 1, 2019, issue of *JAMA Neurology*, Mayo researchers reviewed cases associated with other causes of myelopathy, including spinal dAVF, as a control.

“When looking over case after case of spinal dAVF, this recurrent imaging pattern stuck out as bizarre,” Dr. Zalewski says. “In these cases, we noticed that the entire circumference of the spinal cord showed enhancement for at least a couple of segments, but within that, there was a very abrupt missing segment of enhancement. It’s almost as if someone took a chunk out of the spinal cord in one very focal spot. We had never quite seen this before.”

The researchers suspect the peculiar imaging pattern is due to inconsistency of the intrinsic venous system of the spinal cord, with the abrupt segments without enhancement potentially having better venous egress routes than the adjacent cord.

The missing-piece sign can potentially result in earlier angiography to confirm a diagnosis of spinal dAVF. Mayo Clinic often initially uses MR angiogram (MRA), followed by angiogram.

“MRA of the spinal canal can usually at least tell us the probable location of the fistula,” Dr. Zalewski says. “Our interventional radiologist can then perform an angiogram at more targeted levels to find the exact location and consider embolization, rather than going to every single level in the spinal canal, which can take some time.”

Spinal angiogram is a highly specialized procedure. “Locating a malformation in these tiny blood vessels requires experience,” Dr. Lanzino says. “At Mayo Clinic, we have seen quite a few patients who had an angiogram elsewhere, but the fistula wasn’t detected.”

In Mayo Clinic’s missing-piece study, 5 of 19 patients with the imaging sign required more than one angiogram to confirm a diagnosis of spinal dAVF. “If there is a strong suspicion clinically and radiologically for spinal dAVF — even if the fistula isn’t obvious on a first screen — it’s important to be vigilant and look harder,” Dr. Zalewski says.

The consequences of delayed diagnosis of spinal dAVF were demonstrated by Mayo Clinic researchers in a study published in the February 2016 issue of the *American Journal of Neuroradiology*. The researchers reviewed initially misdiagnosed cases of spinal dAVF ultimately seen at Mayo Clinic between 2000 and 2014. The
median delay before an angiographically confirmed diagnosis of spinal dAVF was six months. All 53 patients in the cohort could ambulate independently at the time of their initial imaging studies demonstrating a spinal dAVF. More than half of the patients in the cohort required a wheelchair or a walker by the time the spinal dAVF was recognized. This progression of disability was usually irreversible; only one-third of patients who required a wheelchair at the time of spinal dAVF diagnosis were able to ambulate with a walker 90 days after treatment.

Finding specific answers

As a tertiary center, Mayo Clinic has experience with spinal epidural AVFs, a rare but treatable subtype of spinal dAVF. Spinal epidural AVFs are the result of a fistulous connection between the branches of the paraspinal or paravertebral arterial system and the epidural venous plexus. Like spinal dAVFs, spinal epidural AVFs often initially present with vague symptoms, such as leg dysesthesia and exertional leg weakness, that progress slowly to severe myelopathy with paraplegia and sphincter dysfunction.

“A multidisciplinary approach and an experienced team are critical, as a neurosurgeon might see only a handful of these cases over the course of a career,” Dr. Lanzino says. As reported in the May 2017 issue of the Journal of Neurosurgery: Spine, Mayo Clinic successfully treated the majority of spinal epidural AVFs seen there between 2005 and 2015 with endovascular therapy alone. Among all the patients treated for spinal epidural AVF, nearly two-thirds experienced some improvement in disability and motor function after treatment, and more than half of treated patients had some improvement in sensory symptoms.

“At Mayo Clinic, we try our absolute hardest to give a definitive diagnosis for patients,” Dr. Zalewski says. “We look for additional clues in tough cases, and we are able to confer and collaborate with our colleagues. Rather than putting patients into a vague category, our goal is always to find a very specific answer.”

For more information


Idiopathic Transverse Myelopathy: Pinpointing the Cause

Compressive and inflammatory myelopathies have diverse etiologies that are often overlooked. As a tertiary center with extensive spinal expertise, Mayo Clinic is able to give most patients more-specific and accurate diagnoses, reducing the risk of disability and of complications due to inappropriate treatment.

“We’ve shown that in about 70 percent of cases, we are able to find a cause and get the patient onto the right treatment plan,” says Eoin P. Flanagan, M.B., B.Ch., a neurologist at Mayo Clinic in Rochester, Minnesota. That finding, based on a review of idiopathic transverse myelitis cases referred to Mayo Clinic from 2010 to 2015, was published in the Jan. 9, 2018, issue of Neurology.

Mayo Clinic’s diagnostic expertise is supported by the enterprise’s innovative spinal cord imaging and antibody testing. “The imaging patterns of various myelopathies that have been found by our researchers are extremely helpful when assessing patients. An analysis of cerebrospinal fluid and serum for certain antibodies — some of them discovered at Mayo — can also help establish if the cause is related to an inflammatory process,” says Sebastian Lopez, M.D., a neurologist at Mayo Clinic in Jacksonville, Florida.

All three Mayo Clinic campuses use a multidisciplinary approach that involves neurosurgeons and other specialists to provide patients with a diagnosis and treatment plan within a matter of days.

“Optimal patient outcomes can be achieved when there is rapid recognition that the clinical problem is a myelopathy, followed by use of a comprehensive algorithmic approach to diagnosis,” says Dean M. Wingerchuk, M.D., a neurologist at Mayo Clinic in Phoenix/Scottsdale, Arizona.” Categorizing the problem as compressive, inflammatory, infectious or related to
another cause is an essential step toward a more specific diagnosis and an appropriate treatment plan.”

**Efficient, multidisciplinary care**

As a fully integrated center, Mayo Clinic coordinates patients’ appointments across specialties. A multidisciplinary team reviews any outside imaging and might order additional MRI investigations. Mayo Clinic has published several studies describing unique imaging patterns associated with various myelopathies, including spondylosis (Figure 1), spinal dural arteriovenous fistula (dAVF), spinal cord sarcoidosis (Figure 2) and neuromyelitis optica spectrum disorders.

“We’ve recognized imaging patterns in hundreds of patients who come to us with unusual presentations. Based on that experience, imaging often guides us in the direction of additional testing and evaluations,” Dr. Flanagan says. “For example, if we suspect sarcoidosis, we might pursue a CT scan of the chest and bring in our pulmonary colleagues.”

Mayo Clinic has also pioneered antibody testing for the diagnosis of inflammatory myelopathies, including the first test available in the United States to identify the myelin oligodendrocyte glycoprotein (MOG) antibody in patient serum. The MOG antibody can distinguish a spectrum of autoimmune demyelinating diseases from multiple sclerosis (MS).

Diseases associated with the MOG antibody and with the aquaporin-4 (AQP4) antibody — also discovered at Mayo Clinic — are commonly misdiagnosed as MS.

“Detection of one of these antibodies at first presentation not only allows for specific early diagnosis but also the development of a preventive treatment plan, because the antibody profile contributes to our ability to predict whether a patient is likely to have future relapses,” Dr. Wingerchuk says.

Autoimmune testing is performed by Mayo Clinic Laboratories. “Our experience with this testing means we avoid mistakes that sometimes occur, such as performing testing after a plasma exchange, which can lead to a false-negative result,” Dr. Flanagan says. “Our lab can perform these tests and provide results usually within a week.”

Accurate diagnosis is essential to prevent complications. For example, the steroids prescribed to treat inflammatory myelopathy can lead to profound disability for people who actually have a spinal dAVF.

“We also see patients who were put on immunosuppressant medications for a suspected inflammatory myelopathy who ultimately received an alternative diagnosis that did not require administration of immunotherapy. Achieving a specific diagnosis is crucial, as chronic immunosuppression can lead to serious infections,” Dr. Lopez says.

Once the cause of an idiopathic myelopathy is correctly identified, Mayo Clinic’s multidisciplinary
All three Mayo Clinic campuses have neurosurgeons who specialize in the treatment of spinal deformity. Working with colleagues in related specialties, Mayo’s highly trained neurosurgeons provide comprehensive care for the full range of spinal deformities in children and adults.

“We treat all spinal deformities — both severe and more-typical cases, in younger as well as older patients,” says Jeremy L. Fogelson, M.D., a neurosurgeon at Mayo Clinic in Rochester, Minnesota. The outcomes can be striking (Figure 1).

Following Mayo Clinic’s team approach, specialists in neurology, physical medicine and rehabilitation, and pain medicine work with neurosurgeons on the initial evaluations of people with spinal deformities. For small deformities associated with mild back pain, physical therapy and injections are generally the initial treatment recommendations. When surgery is indicated, Mayo Clinic uses minimally invasive surgery when appropriate, as well as robotic guidance, intraoperative monitoring and navigation to minimize the risk of complications.

“Our technology helps us to optimize treatment outcomes. The precise placement of instrumentation results in more-effective stabilization of the spine, which minimizes the need to return to the operating room for corrective surgery,” says Eric W. Nottmeier, M.D., medical director of the spine center at Mayo Clinic in Jacksonville, Florida.

As a high-volume center for spinal deformity, Mayo Clinic has experience with the range of treatment options. “The surgeons at all three of our campuses have the training and insight to utilize team can provide treatment. “We work closely with our neurosurgeons in cases of a vascular or spondylotic myelopathy,” Dr. Flanagan says. “Treatment outcomes from myelopathies can be good, depending on the cause and when appropriate treatment is initiated. If there is any uncertainty about the cause of myelopathy, a referral to Mayo Clinic can result in an accurate diagnosis and intervention that will prevent harm.”

For more information

Specialized Expertise for Spinal Deformity Surgery

Figure 1. A. Lateral X-rays show the best upright posture of a 70-year-old man with Parkinson’s disease and severe kyphotic and scoliotic deformities above and below a previous fusion, including a cervical kyphosis. Obtaining this view required piecing together several X-rays. In addition to the severely abnormal posture, the patient experienced significant leg pain from a pinched nerve in the low back. B. Postoperative X-rays show corrected alignment. Surgery was performed in a single-stage operation through the posterior approach, stabilizing and fusing much of the spine. The surgery greatly improved the patient’s ability to perform daily activities.
technology appropriately, in ways tailored to the needs of the patient. We decipher who is going to do best with a particular technology,” says Jamal McClendon Jr, M.D., a neurosurgeon at Mayo Clinic in Phoenix/Scottsdale, Arizona. “That training allows us to deliver a consistent quality of care, irrespective of region.”

**Options for all types of care**

The wide range of spinal deformity treated at Mayo Clinic encompasses all forms of scoliosis and kyphosis, high-grade spondylolisthesis, and cervical spine and post-laminectomy deformity, as well as revision surgeries. Intraoperative monitoring to measure neural function and integrity is performed by highly trained technicians and monitored by a neurophysiologist on-site. Three-dimensional spinal navigation is used to guide the placement of spinal hardware, and intraoperative CT to check screw placement.

All members of the patient care team have spinal deformity expertise, including nurses and anesthesiologists dedicated to caring for patients during complex spinal procedures. Postoperative care and rehabilitation are provided by physical medicine and rehabilitation specialists, pain specialists, and physical and occupational therapists who routinely work with people who have spinal deformity surgery.

Before or after surgery, Mayo Clinic can provide additional care to improve bone health. “A large proportion of patients with spinal deformities have osteopenia or osteoporosis. We partner with our endocrinologists in these cases because we believe that optimal management requires working with specialists dedicated to bone metabolism and bone health,” Dr. Fogelson says.

Mayo Clinic’s expertise facilitates optimal outcomes even in the most challenging cases. Dr. Fogelson cites a healthy 12-year-old girl who experienced progressive difficulty maintaining upright posture, as well as leg pain, weakness and numbness (Figure 2). The pain worsened with standing and walking, forcing the girl to stop playing sports. After a diagnosis of spondylolisthesis, nonoperative treatments failed to resolve the patient’s pain. Surgery performed by a combined neurosurgical and pediatric orthopedic team utilized a single-stage posterior approach.

“The patient is three years out from surgery, and her symptoms have completely resolved,” Dr. Fogelson says.

Mayo Clinic also has extensive experience with severe curvature in younger adults (Figure 3). Many of these patients had scoliosis as children. “Although these patients are relatively young and otherwise healthy, they can experience a lot of pain, and benefit from surgery,” Dr. Fogelson says.

For physicians considering referral to Mayo Clinic, Mayo’s neurosurgeons are able to discuss cases by telephone or electronically. “At Mayo Clinic, we have the breadth and depth of expertise to utilize multiple strategies for spinal deformity, irrespective of the complexity,” Dr. McClendon says. “Our care is always individualized to the patient.”

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**Figure 2.** A. X-ray, CT and MRI demonstrate grade 5 spondylolisthesis of L5 on the sacrum in a 12-year-old girl. B. On the left, a preoperative X-ray shows misalignment. On the right, a postoperative X-ray shows nearly normal alignment.

**Figure 3.** On the left, preoperative X-rays show spinal curvature in a 53-year-old woman who presented at Mayo Clinic with pain in her right leg, low back and ribs. As a child, the patient developed scoliosis, which progressed slowly over the years. After confirming that nonsurgical management wouldn’t adequately treat her pain, Mayo Clinic neurosurgeons performed a spinal fusion in a single surgery through a posterior approach. On the right, postoperative X-rays show the result.
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Mayo Clinic, Rochester, Minn.

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Nov. 7-9, 2019
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Information and registration
Mayo Clinic in Rochester, Minnesota
Phone: 800-323-2688 (toll-free) or 507-284-2509
Email: cme@mayo.edu

Mayo Clinic in Jacksonville, Florida
Phone: 800-462-9633 (toll-free) or 904-953-0421
Email: cme-jax@mayo.edu

Mayo Clinic in Phoenix/Scottsdale, Arizona
Phone: 480-301-4580
Email: mca.cme@mayo.edu

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

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