MAYO CLINIC

OrthopedicSurgeryUpdate

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INSIDE THIS ISSUE

Vertebral Column Resection: Multidisciplinary Approach to Complex Spinal Deformity

As a high-volume center for spinal deformity care, Mayo Clinic has the expertise required to treat even the most challenging conditions. Orthopedic surgeons routinely work alongside neurosurgeons and other specialists to optimize outcomes and enhance patient safety in complex procedures such as vertebral column resection (VCR).

"The Mayo Clinic care model is designed to allow different subspecialties to work together to care for complicated patients. That has been a long-standing and successful strategy for great patient care," says Anthony A. Stans, M.D., a pediatric orthopedic surgeon and surgeon-in-chief of the Mayo Clinic Children's Center in Rochester, Minnesota.

This multidisciplinary approach to VCR and other complex spinal procedures incorporates extensive pre-surgical planning and the latest imaging technology. A high-resolution CT scan of the spine deformity is acquired. The image data is then exported into spinal surgery planning software developed by Mayo's Biomedical Imaging Resource Core and Paul M. Huddleston III, M.D., a Mayo orthopedic spinal surgeon. The software allows surgeons to analyze individual vertebrae and virtually place pedicle screw implants in the optimal position within each vertebra (Figure 1).

Mayo's 3D anatomic modeling laboratories export the surgical planning images to a 3D printer, which prints a life-size model with pedicle screw holes in optimal locations. A complete pre-surgical model can be created in just one to two days.

"The model is very helpful on several levels," Dr. Stans says. "The process forces us to analyze every single vertebra and decide whether screws can be placed safely. Effectively performing pedicle screw placement on the computer in advance of the operation, and identifying the optimal starting point, trajectory and screw size, saves time and increases safety during surgery."

Figure 1. Mayo Clinic's software allows orthopedic surgeons to place screws directly onto a patient's CT scan, as part of surgical planning.

The 3D model is brought into the operating room and referred to during the procedure.

Additional technology and expertise in the operating room help further ensure a successful outcome. Intraoperative spinal cord monitoring is performed by highly trained technicians and monitored by a neurophysiologist on-site. Anesthesiologists with special interest and expertise

Anthony A. Stans, M.D.

in spinal surgery use an anesthesia protocol to optimize the accuracy of spinal cord monitoring, minimize blood loss and maximize postoperative pain control. Intraoperative CT and computer navigation are used to guide the placement of pedicle screws.

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.

"Our experience and collaboration across specialties allow us to treat all types of spinal deformities, in patients of all ages," Dr. Stans says.

This technology and expertise help provide excellent outcomes for even the most challenging deformities. Dr. Stans cites a young woman whose severe scoliosis was corrected at Mayo Clinic (Figure 2). "With a curve this severe, she was becoming increasingly short of breath," he says. "She sang in her university choir but found she could no longer hold a long note very well."

Dr. Stans performed a VCR alongside Jeremy L. Fogelson, M.D., a Mayo Clinic neurosurgeon who has complementary expertise in complex spinal surgeries. The two surgeons routinely perform VCR together.

After surgery, the patient quickly found that she could fill her lungs (Figure 3). "Six months after surgery, she went on a 6-mile hike in the Cascade mountains," Dr. Stans says.

Several years before coming to Mayo Clinic, the patient had been seen elsewhere and advised to undergo corrective surgery. But she and her family were reluctant to proceed with the procedure recommended there, as it involved a thoracotomy, anterior release and partial vertebrectomy, followed by posterior instrumentation and fusion.

"At Mayo, we do VCR with one incision, as a staged procedure over two days," Dr. Stans says. "This strategy allows us to do the initial steps of the operation on the first day, and then perform the most challenging parts early on the subsequent day when the patient is in optimal medical condition and the surgical team is fresh and at the top of their game."

In the years before coming to Mayo Clinic, the patient's deformity had worsened. At the same time, her younger sister also developed severe scoliosis. The sister came to Mayo Clinic first and had scoliosis surgery.

"After the younger sister's successful surgery, the older sister decided to go ahead with the VCR operation," Dr. Stans says. "At Mayo Clinic, the combination of advanced technology, specialized expertise and collaboration across medical specialties allows us to successfully and safely care for patients with complex spinal deformity."

Figure 2. Photograph shows a 3D-printed image of the patient's spine before vertebral column resection at Mayo Clinic.

Figure 3. A. Preoperative radiograph shows severe scoliosis. **B.** Postoperative radiograph shows excellent correction following vertebral column resection and posterior spinal instrumentation.

Executing the Preoperative Plan: Computer-Guided Shoulder Arthroplasty

Although preoperative planning for shoulder arthroplasty is common, surgeons performing the procedure are often unable to precisely position the component in vivo. Mayo Clinic's campus in Florida uses computer-guided intra-operative navigation to help ensure the proper placement of glenoid components.

"You can plan extensively. But without intra-operative navigation, it's difficult to replicate the planned component position. With intraoperative guidance, we can get the component to the spot where we want it to be," says Bradley S. Schoch, M.D., an orthopedic surgeon at Mayo Clinic in Jacksonville, Florida.

Dr. Schoch has been performing computer-guided shoulder arthroplasty for about three years. Long-term data are needed to determine the effect of component navigation on clinical outcomes. However, it's well established that implant retroversion exceeding 10 degrees can cause component loosening. That type of positioning error is common, according to Dr. Schoch's research.

In a retrospective review of primary shoulder arthroplasties, Dr. Schoch and colleagues from the University of Florida observed component malposition in 48% of shoulder arthroplasty cases performed using 3D preoperative planning without navigation. The errors were accentuated in surgeons without completed fellowship training. But even in cases performed by fellowship-trained attending surgeons, the malposition rate was 38% without navigation.

"We know that even experienced surgeons can be inconsistent in replicating the planned component placement," Dr. Schoch says. "With intraoperative technology, we can eliminate those outliers."

The researchers defined component malposition as displacement of more than 4 millimeters, or an error in version or inclination of more than 10 degrees. The surgeries were planned using both multiplanar 2D CT and 3D implant overlays.

Computer-guided shoulder arthroplasty can be especially helpful for patients with severe bone loss or abnormal socket architecture. The intraoperative guidance provides real-time data relative to the pre-surgical plan (Figure).

"The line-of-sight guidance allows us to line up our procedure with the pre-surgical plan, using a target on a screen," Dr. Schoch says.

He and his research colleagues plan further studies comparing computer-guided shoulder arthroplasty in patients with varying types of glenoid morphology, such as biconcave glenoid. "The visual landmarks of the scapula are limited intraoperatively," Dr. Schoch says. "The inability to accurately execute a preoperative plan may increase the risk of component failure. With intraoperative guidance, you can put it where you plan it."

Bradley S. Schoch, M.D.

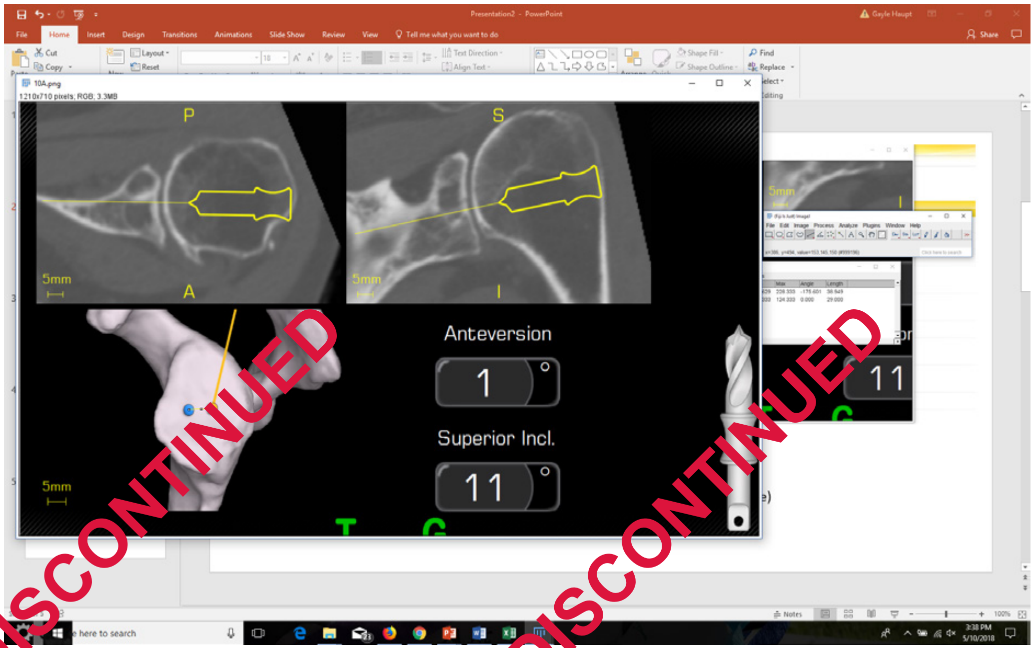

Figure. Intraoperative guidance matches the placement of surgical components to the preoperative plan, including angle measurements (blue circle).

Revision ACL Surgery: A Comprehensive Approach

Bruce A. Levy, M.D.

Approximately 200,000 anterior cruciate ligament (ACL) ruptures occur in the United States annually. Primary ACL reconstruction is recognized as a successful procedure, but failure has been shown to occur in approximately 10% of patients.

Mayo Clinic sports medicine surgeons routinely perform revision surgery for patients who have undergone one or more ACL reconstructions elsewhere, and have published extensively on this topic. Bruce A. Levy, M.D., an orthopedic surgeon specializing in sports medicine at Mayo Clinic in Rochester, Minnesota, discusses Mayo's approach to revision ACL surgery.

What factors does Mayo Clinic consider when evaluating a patient with a failed ACL reconstruction?

We focus on many factors including the status of the menisci, cartilage, alignment, tibial slope and other knee ligaments, as well as technical issues from the index surgery, such as the positioning of ACL sockets and tunnels (Figures 1-3). As our group described in 2013 in *American Journal of Sports Medicine*, all of these factors contribute to ACL failure and to the success of revision ACL surgery.

We routinely obtain hip-to-ankle AP X-rays to assess for any coronal plane malalignment. In addition, we obtain single leg knee-to-ankle lateral X-rays to assess for any sagittal plane malalignment as well as to look for excessive tibial slope.

There are numerous challenges to revision ACL surgery with regard to graft selection, timing of surgery, and whether or not the surgery can be performed in a single operation or multiple-staged surgeries. Optimal outcomes require a precise picture of how the ACL reconstruction failed. At Mayo Clinic, we have the imaging, surgical and physical therapy teams to manage extremely complex knee issues.

What causes do you commonly see?

Unfortunately, the most common cause for failure is related to technical issues from the primary ACL surgery, with malposition of the sockets and tunnels, particularly on the femoral side. Achieving the correct position can be tricky.

Meniscal tears are another contributing cause. Often the meniscus hasn't healed after the initial surgery, or lesions might have been overlooked during surgery, in particular meniscal root tears or meniscal ramp lesions.

These lesions are often difficult to see on MRI. Unless the surgeon looks specifically for a ramp lesion at the time of ACL surgery, the lesion can be missed. Ramp tears can lead to rotational instability and put excessive strain on the ACL graft, causing it to fail. Similarly, root tears of the lateral meniscus are often missed as well. Unless you probe for a root tear during surgery, you may miss it. Root tears also put tremendous forces on the ACL graft and can lead to rotational instability and graft failure.

What issues do you see with alignment?

Varus or valgus malalignment can put strain on an ACL graft, whatever the malalignment's cause — the patient's physiology, failed meniscal surgery or cartilage problems. At Mayo Clinic,

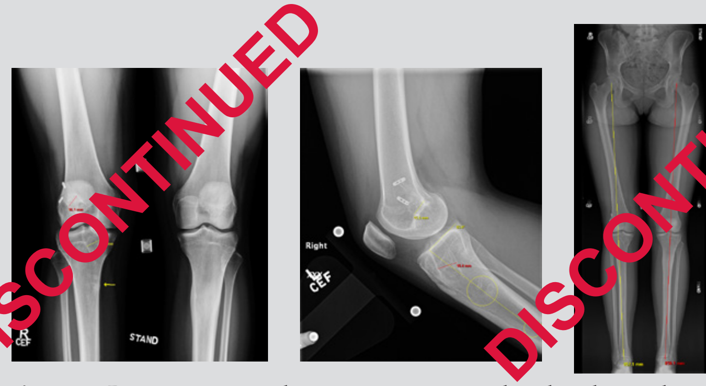

Figure 1. Pre-op imaging shows excessive tunnel and socket widening and no malalignment with normal slope.

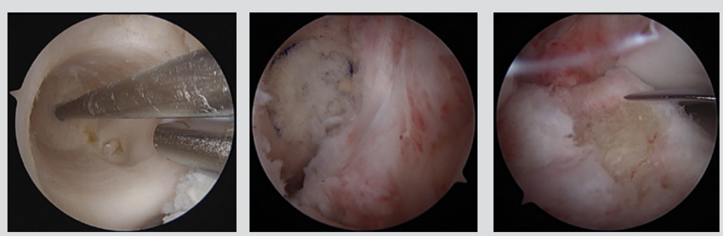

Figure 2. Stage I femoral and tibial bone grafting.

Figure 3. Stage II lateral root tear, lateral root repair and repeat revision back-to-back ACL repair.

we sometimes correct the alignment before performing revision ACL surgery, to prevent graft failure.

Excessive tibial slope also puts patients at much higher risk of early ACL reconstruction failure. The slope causes the tibia to move forward and the femur to fall backward, putting tremendous strain on the ACL. The greater the tibial slope, the higher the risk of graft failure — as our group found in a 2015 study in *American Journal of Sports Medicine*. At Mayo Clinic, we frequently perform osteotomies to correct both sagittal plane and coronal plane deformity.

Are these procedures performed in a single surgery, or staged?

A lot of factors help us to determine whether a single revision or a two- or multiple-stage revision would be best for a particular patient. For example, patients may require bone grafting of prior graft tunnels, and then have the ACL revision in a second stage (Figures 2 and 3). The bone grafting is an opportune time to do an osteotomy to correct the malalignment. Sometimes we can perform a biplanar osteotomy to correct both planes of deformity at once. This adds a fair amount of complexity to the procedure.

What other specialized procedures might be performed in conjunction with ACL revision surgery?

Patients who have lost a meniscus or have a significant cartilage defect and have a failed ACL can, in some circumstances, require a meniscus transplant or cartilage replacement surgery. Mayo Clinic has substantial experience with all of these procedures.

In addition, patients who receive revision ACL surgery might have other damaged ligaments. Mayo Clinic has vast experience treating posterior cruciate ligament, lateral collateral ligament, posterolateral and posteromedial corner injuries, as well as medial collateral ligament injuries. If any of those ligaments were missed in the initial knee surgery, they can be treated in the revision setting.

Recently, we recognized that patients needing ACL reconstruction who also have significant rotatory instability of the knee may have injuries in the anterolateral complex. There are several procedures that can be performed in the ACL revision setting, such as anterolateral ligament reconstruction and iliotibial band tenodesis, to control that rotation.

What research is underway?

Several Mayo Clinic orthopedic surgeons are members of the Multicenter ACL Revision Study (MARS) Group, which has authored a series of reports on topics including predictors of clinical outcomes, published in *Journal of Orthopaedic Research* in 2020. At Mayo Clinic, we also are evaluating surgical techniques for ACL reconstruction, as well as optimal approaches to multiligament knee reconstruction. The goal is to ensure patients of all activity levels, from professional to recreational, have the surgeries that meet their individual needs. We want our patients to be able to return to the activities they enjoy.

Can you share a case with us?

A 17-year-old female came to see us after two failed ACL surgeries. Her alignment, tibial slope and cartilage were all normal. Unfortunately, both previous reconstructions were performed with allograft (cadaver) tissue, which has been shown to have significantly higher failure rates in young patients compared with autograft (the patient's own tissue). The patient also had an unrecognized complete disruption of her lateral meniscal root and excessively widened tunnels and sockets.

This case required a two-stage approach: Stage 1 consisted of bone grafting, followed by second-stage repeat revision ACL reconstruction with patellar tendon autograft, lateral meniscal root repair and iliotibial band tenodesis. Two years after the surgery, she resumed all activities and plays collegiate volleyball.

For more information

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Christensen JJ, et al. Lateral tibial posterior slope is increased in patients with early graft failure after anterior cruciate ligament reconstruction. *American Journal of Sports Medicine*. 2015;43:2510.

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Spinal Implant Infections: Enhanced Diagnosis and Prevention

Paul M. Huddleston III, M.D.

Infection complicates up to 3% of major spinal surgeries and is associated with significant morbidity and cost. Those issues stem in part from challenges surrounding the diagnosis of infections after spinal implant surgery. Mayo Clinic has found ways not only to dramatically reduce the rate of surgical site infections after spinal procedures but also to better diagnose infections when they occur.

"These situations are often frustrating for patients and physicians," says Paul M. Huddleston III, M.D., an orthopedic surgeon at Mayo Clinic in Rochester, Minnesota. "The X-rays of patients with spinal implant infections may look normal. But the patients have pain around the implant area. The physicians know the patients aren't doing well, but by the standard measures there appears to be nothing wrong."

Mayo Clinic has a long history of research in orthopedic surgical site infections. "Recently we have worked to broaden the knowledge base from lessons learned with knee replacements and other artificial joints to the area of spine instrumentation," Dr. Huddleston says. "Infections associated with spinal implants can be quite painful. In some instances, they can cause paralysis or be lethal."

In the decade from 2006 to 2016, Mayo Clinic reduced the rate of surgical site infections after spinal surgery by two-thirds (Figure). That decline — described in the February 2019 edition of *The Spine Journal* — was achieved in the context of a large, quaternary center engaged in a disproportionate amount of complex spinal surgery in patients with high morbidity.

Mayo Clinic's bundled approach consisted of five simple and cost-effective surgical protocols:

- Application of intrawound vancomycin powder
- Wound irrigation with dilute Betadine solution
- Preoperative chlorhexidine gluconate scrubs
- Preoperative screening with nasal swabbing and decolonization of *S. aureus*
- Perioperative antibiotic administration

"We can't say which of these individual interventions is most effective," Dr. Huddleston says. "But we clearly showed there's no obvious harm, and an enormous decrease in infection rate, from doing them all in a bundle."

Further research is needed to define the optimal use of prophylactic antibiotics in spinal wounds. "As orthopedic surgeons, we certainly don't want to drive the unwanted development of superbugs. But we are also sensitive to the need to prevent implant-associated infections," Dr. Huddleston says.

Finding elusive bacteria

Many of the organisms commonly implicated in implant infections form biofilms on an implant's surface — making it difficult to obtain a culture from tissue samples alone. A technique developed at Mayo Clinic of vortexing and sonication of implants has demonstrated superior sensitivity and specificity compared with tissue sampling, in many types of orthopedic implants. However, vortexing and sonication has not been widely applied to spinal implants.

Mayo Clinic recently developed a system for testing sonication fluid obtained from spinal implants. "This methodology allows us to blast the biofilm off the spinal implants and culture the bacteria that hide in there," Dr. Huddleston says. "Many patients who do not have access to these types of diagnostics are at risk of being told after tissue sampling that they don't have an infection, when they may in fact have an infection hiding in the biofilm on the implant itself."

In a study published in *Spine* in 2020, Mayo Clinic researchers found that their method of spinal implant sonication is sensitive and specific for the diagnosis of spinal implant infections. Lower thresholds for defining sonicate fluid culture positively allow for increased sensitivity with a minimal decrease in specificity, enhancing the clinical utility of implant sonication.

That study is a part of Mayo Clinic's ongoing research into retained orthopedic implants. As a major clinical and research center, Mayo utilizes the expertise of specialists in infectious diseases and internal medicine as well as orthopedic surgery.

"It's extremely rewarding when we can, in a collaborative fashion, produce a positive outcome for patients that they might not have

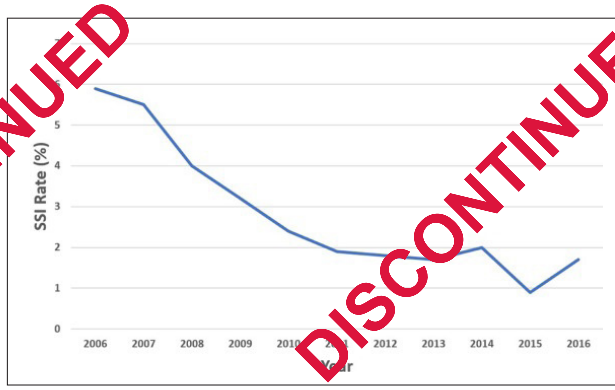

Figure. Mayo Clinic reduced the rate of surgical site infections (SSI) after spinal surgery by two-thirds from 2006 to 2016.

elsewhere," Dr. Huddleston says. "Mayo Clinic is uniquely positioned to help these patients with very challenging conditions."

For more information

Tomov M, et al. An empiric analysis of 5 counter measures against surgical site infections following spine surgery — A pragmatic approach and review of the literature. *The Spine Journal*. 2019;19:267.

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Incisionless, Ultrasound-Guided Approach for Carpal Tunnel Release

Mayo Clinic is one of the few orthopedic surgery centers that offer ultrasound-guided intervention for carpal tunnel release. The minimally invasive treatment, which uses a thread to dissect the transverse carpal ligament, is done under local anesthesia.

"The approach is designed to minimize soft tissue dissection and injury," says Alexander Y. Shin, M.D., an orthopedic surgeon at Mayo Clinic in Rochester, Minnesota. "Mayo Clinic has performed about 75 of these procedures, and the outcomes are very good. Patients recover in about two weeks instead of the four to six weeks needed after open surgery."

Carpal tunnel syndrome is common, and an estimated 71% of patients receive surgical intervention as their primary treatment. The estimated cost of medical care for carpal tunnel syndrome in the United States is $2 billion a year, with median lost work times of just under 30 days. Surgical treatment most often involves an open procedure. Endoscopic approaches are usually associated with less postoperative pain and a faster return to work, but also with increased risk of nerve injury and incomplete release.

The incisionless technique — known as thread ultrasound-guided carpal tunnel release (Figures 1-5) — is performed by Dr. Shin and Jeffrey S. Brault, D.O., a physical medicine and rehabilitation specialist at the Rochester campus of Mayo Clinic.

Alexander Y. Shin, M.D.

Ultrasound is used to identify the medial nerve at the level of the wrist, and to determine an entry point in the palm and exit point in the wrist for specialized needles used in the procedure. Those sites are anesthetized. Under continued ultrasound guidance, a modified Tuohy needle is passed under the carpal tunnel and above the median nerve by hydrodissection. The needle's tip is pushed above the exit point, and a cutting thread is passed through the needle. The Tuohy needle is then passed above the carpal ligament using the same entrance and exit needle holes as the first needle pass, and the cutting thread is passed through the needle.

"That creates a complete loop around the ligament, with no incision," Dr. Shin says. "Then, under direct visualization, we pull the two threads back and forth to cut the ligament." The procedure takes about 10 to 15 minutes.

Afterward, the patient has two needle holes that are dressed with a small adhesive dressing. The patient can remove the dressing after 24 hours and start gentle activities as tolerated.

Dr. Shin notes that one of his patients had the incisionless procedure to treat carpal tunnel syndrome so severe that the pain consistently woke him at night. The patient was unable to take the weeks off work that are generally needed after open surgery.

"We did the procedure, and he was back at work the next day," Dr. Shin says. "This is an innovative technique that is changing patients' lives."

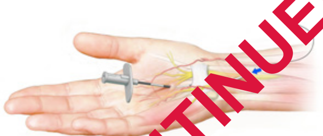

Figure 1. Under ultrasound guidance, a needle is passed under the carpal tunnel and above the median nerve, and a cutting thread is passed through the needle's tip.

Figure 2. The needle is passed above the carpal tunnel, using the same entry and exit points as the first pass.

Figure 3. Cutting thread is again passed through the needle, creating a loop.

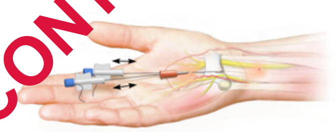

Figure 4. The ends of the cutting threads are gently tugged to cut the ligament.

Figure 5. The carpal tunnel ligament has been severed with an incisionless procedure.

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Artificial Intelligence: Potential To Improve Knee Arthritis Care

Although artificial intelligence is upending medical care, its potential applications to orthopedic surgery haven't been widely studied. Mayo Clinic found that a deep learning algorithm can identify and classify knee osteoarthritis on radiographs as accurately as fellowship-trained knee arthroplasty surgeons.

"This technology has the potential to significantly decrease the likelihood of inaccurate assessment of radiographs in the diagnosis and treatment of knee arthritis," says Adam J. Schwartz, M.D., an orthopedic surgeon at Mayo Clinic in Phoenix/Scottsdale, Arizona. "There is currently no standardized approach, and quite a bit of variability, in reading these radiographs. Reducing that variability can facilitate clinical decision-making and improve outcomes for patients."

The researchers trained a convolutional neural network to identify critical aspects of radiographs indicating knee osteoarthritis and to rate the severity of the condition using the International Knee Documentation Committee scoring system. Four orthopedic surgeons were then asked to evaluate 676 knee radiographs taken from consecutive patients who made routine visits to Mayo's orthopedic clinic.

The surgeons' ratings were compared to one another and to the neural network's ratings of those 676 knees. Statistical analysis found broad agreement between the assessments from the surgeons and the artificial intelligence tool.

"A convolutional neural network can accurately identify the critical components of a standing posterior-anterior flexion knee radiograph without human control," Dr. Schwartz says. "In many instances in our study, the neural network correlated to a surgeon more accurately than many surgeon-to-surgeon comparisons."

Deep visual learning

A convolutional neural network is a type of deep learning tool that is commonly used to evaluate visual imagery. Deep learning is a method of artificial intelligence that processes raw data — such as images — with learning algorithms to create layers of nodes, each receiving information from, and learning from, the other.

Adam J. Schwartz, M.D.

"Before implementing this type of solution in clinical practice, we need more data and additional training, to minimize the potential for errors in classifying the severity of osteoarthritis," Dr. Schwartz says. "But once you have an artificial intelligence model, you can find all sorts of ways to improve efficiency and reduce variability."

Mayo Clinic's ability to perform this type of cutting-edge research rests on the center's multidisciplinary expertise. In addition to Dr. Schwartz and other orthopedic surgeons, Matthew R. Neville, M.S., a Mayo Clinic biostatistician with experience in full-stack web development and artificial intelligence techniques, participated in the project.

"Developing convolutional neural network models takes quite a lot of data," Mr. Neville says. "To assist with data collection, we designed a variety of web-based tools that made it relatively painless for the surgeons to assess radiographs."

This multidisciplinary approach facilitates research that ultimately benefits patients. "Combining expertise allows for the sum to be greater than each part," Dr. Schwartz says. "We see this technology as facilitating shared decision-making by patients and physicians about surgical and nonsurgical interventions."

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