Anterior cruciate ligament (ACL) tear is a common knee injury in active people and athletes. An estimated 200,000 ACL ruptures occur each year in the U.S., with an annual incidence of primary ACL reconstruction of approximately 34 per 100,000 individuals. While the primary reconstruction procedure has a notable success rate, in approximately 7 percent to 10 percent of cases the ACL graft fails. Mayo Clinic outcomes research and large national studies show that results from revision surgery are inferior to those of the primary procedure—and worsen with multiple revisions. (See MARS cohort sidebar.)

To help overcome these limits to revision ACL reconstructions, Mayo Clinic Orthopedics sports medicine specialists are recognizing new approaches. “Our goal is to improve ACL reconstruction and revision results that have been modest for certain patients,” explains Aaron J. Krych, M.D., Mayo Clinic orthopedic surgeon and sports medicine specialist. Adds his colleague, Michael J. Stuart, M.D., co-director of sports medicine: “We want to determine why revision results are inferior to primary ACL reconstruction and what can we do to improve success.”

**Missing Links**

Two reasons for inferior results in the revision setting that have not received widespread attention are excessive lateral tibial posterior slope (LTPS) and damage to the anterolateral ligament (ALL). “These are things we may have been previously missing in these patients,” Dr. Krych says.

“If we can correct these, it seems likely we can improve outcomes,” explains Bruce A. Levy, M.D., Mayo Clinic orthopedic surgeon and sports medicine specialist.

**When to Consider ALL Reconstruction**

- Failed ACL reconstruction
- Multiple revised ACL knee
- Chronic ACL deficiency
  — ALL has not healed?
- Large 3+ pivot shift
- “High-risk knee”
  — Female, hyperextension, soccer

**Figures 1A&B.** Fig. 1A Single-leg stance lateral radiograph of the tibia demonstrates posterior slope of 25 degrees and anterior translation of 12 mm prior to surgery. Fig. 1B Radiograph two years following osteotomy and revision ACL reconstruction with restoration of slope and improved anterior translation.
Tibial Slope Impact

Mayo’s research shows that an increased lateral tibial slope puts more stress on the ACL and allows the tibia to slide forward. This impairs stability and can undermine ACL surgery success. To correct this, the Mayo team has utilized a bony procedure for selected patients that decreases the slope through a realignment osteotomy (Figure 1).

Explains Diane L. Dahm, M.D., Mayo Clinic orthopedic surgeon who specializes in sports medicine: “In our studies, we noted a 2.4 times increased risk for graft failure with a 4-degree increase in slope, and nearly a four times increased risk for failure with a 6-degree increase in slope” (Figure 2).

Results suggest that in women tibial slope represents more of an independent risk factor for early graft failure than for primary ACL tear. “This effect appears to have a magnitude-response relationship, with escalating risk for graft failure with increasing posterior slope,”

Figure 2. Graph showing that as lateral tibial slope increases over 6 degrees, there is a marked increase in graft failure. Solid line represents probability of graft failure related to tibial slope. Dotted lines represent the 95 percent confidence interval.

MARS Cohort and Mayo Clinic ACL Multiple Revision Study

The Multicenter ACL Revision Study (MARS) cohort is the largest focused study of the ACL reconstruction population. The explanatory power of a large sample size produces more statistically valid results to aid clinical decision-making.

By spring of 2009, MARS enrolled 87 surgeons, including the Mayo Clinic sports medicine team, with a total of 460 patients (57 percent men; median age, 26 years). Their goal: to better assess the results of ACL revision surgery and determine predictors of outcome.

MARS results show that ACL reconstruction revisions are inferior to primary surgery and that outcomes worsen as the number of revisions increases. Importantly, MARS identified major causes of failure, with traumatic reinjury the most common. Graft choice also plays a role.

In 2013, the Mayo Clinic sports medicine team of Diane L. Dahm, M.D., Bruce A. Levy, M.D., and Michael J. Stuart, M.D., published a smaller study of 15 Mayo patients who had at least two revision ACL reconstructions. Mean age was 27 years (range, 18-57 years). Mean follow-up was five years (range, 2-10 years). Results support the MARS findings, showing that while clinical outcome improved, results of revision surgery were inferior to primary surgery because patients did not return to prior activity levels after multiple revision surgeries.
Dr. Dahm says. “For carefully selected patients with significantly increased posterior slope, Mayo surgeons have used osteotomies to improve ACL revision outcomes.”

**Avulsed ALL and ACL Tears**
As early as 1870, French physician Paul Segond noted that an extra-capsular ligament was involved in stabilizing the knee against rotary forces. Up until the 1980s, this interest in extra-capsular ligaments’ role in stability persisted.

But with the rise of the arthroscope, focus on the intra-articular anatomy, including visualization of the ACL, came to dominate investigations. In the process, these extra-articular contributions to knee stability were overlooked.

But this extra-capsular ligament, now referred to as the anterolateral ligament (ALL), is a focus of renewed attention. It is now understood to play a key role in controlling rotary knee instability and pivot-shift. Says Dr. Krych: “If you examine the ALL ligament in the lab, you can’t fully recreate the full grade III pivot-shift by just sectioning the ACL. You have to tear both the ACL and this ALL. What this suggests is that a ruptured ALL is a prerequisite for grade III pivot-shift in the ACL-deficient knee and that the ALL must be also repaired to achieve full ACL stability.”

He speculates that a torn ALL heals by itself in most patients, which is why, overall, ACL patients do so well. However, the rare cases in which a ruptured ALL fails to heal by itself appear to be one driver of ACL healing failures. “In the revision setting, this tear is probably another thing we’ve been missing,” Dr. Krych says.

**Rediscovering ALL**
In 2013, a Belgian research team “rediscovered” the importance of the ALL through a cadaveric study of 40 knees. The ALL structure underwent dissection from extra- and intra-articular perspectives for detailed anatomic and biomechanics evaluation.

The Mayo team is currently at work further refining the diagnosis, treatment, surgical indications and technique for ALL reconstruction to decrease persistent rotational laxity after ACL revision and reconstruction.

Says Dr. Krych: “We haven’t been looking for it on MRI and you can’t really feel it on exam. But it’s been there, and now that we have evidence that implicates it in ACL graft performance, we’re devising ways in select cases to reconstruct it in hopes of bringing every ACL reconstruction patient a better outcome.”

**Figure 4.** Cadaveric dissection photograph of ALL anatomy reveals its origin at the lateral epicondyle, running obliquely to insert just distal to the lateral joint line, halfway between fibular head and Gerdy’s tubercle.

**Figure 5.** Photographic series showing evolution of surgical technique based in principles of ligament reconstruction shows larger open incision and two small, percutaneous incisions to reconstruct ALL with single-limb gracilis autograft tendon.
Reverse Total Shoulder Arthroplasty Indications Expanding, Outcomes Improving

Mayo Clinic Orthopedic shoulder team has pioneered refinements in reverse shoulder arthroplasty (RSA) since 2004—the year the procedure was first approved for American use by the U.S. Food and Drug Administration. Over the past decade, Mayo contributions have improved implant designs, operative technique and preoperative management while strengthening the research base with outcome studies. As a result, Mayo’s leadership has helped RSA to become one of the fastest-growing specialty surgeries of orthopedic shoulder care, explains John W. Sperling, M.D., Mayo Clinic orthopedic surgeon.

“RSA has come a long way, and is an exciting advance because it has made a dramatic impact on how we can improve the quality of life for our patients. It’s a very viable option in carefully selected populations operated on by experienced teams,” Dr. Sperling notes. For example, massive rotator cuff tears or patients with poor bone stock thought to be untreatable in the past have been successfully treated by RSA (Figure 1). Patients with failed implants are also benefiting from this new treatment.

“Mayo Clinic Orthopedics now does more reverse shoulder arthroplasties than any other institution in the world, treating patients from around the world,” he says. Dr. Sperling estimates greater than 600 RSAs are performed annually throughout Mayo Clinic.

Advances and Improvements

Chief among the highlights in RSA evolution are:

1. Broadened indications to take care of a wider range of shoulder disorders.
   “In the past, this group of patients with rotator-cuff deficiencies, poor bone stock and pre-existing trauma were faced with minimal to no options,” Dr. Sperling says. “The reverse shoulder technique is a very viable option that’s become more predictable to help them attain pain relief and improve their function.”

   Expanded indications include:
   • significant or severe bone loss
   • unstable and failed shoulder replacements
   • massive rotator-cuff tears with the inability to raise the arm
   • selected proximal humeral fractures
   • complex sequelae of trauma in the shoulder region

Patients with an intact rotator cuff and intact bone stock may be more appropriate for traditional approach. Mayo Clinic Orthopedic’s comprehensive preoperative evaluation helps direct patients to the optimal approach.

2. Fewer complications

The Mayo team credits reduced complications to better designs and improved technology to gain secure fixation into the bone that can accommodate for rotator-cuff deficiency and/or glenoid-bone deficiency. Use of the short-stem uncemented bone-preserving implant is one such advance. Another is increasing use of patient-specific instrumentation to more accurately place the components. “By using a preoperative CT scan to make the custom guide, we can optimize placement to a degree never before possible,” Dr. Sperling says (Figure 2).

3. More efficient surgery and recovery—discharge in 48 hours

Mayo Clinic’s orthopedic team has developed

Rationale for Reversing Anatomy

RSA reverses the natural anatomy of the ball-and-socket shoulder joint by implanting a concave socket plate into the humeral head, and a convex spherical glenoid component into the glenoid fossa. The goal is to overcome vulnerabilities of traditional shoulder replacements in which the absence of a stabilizing rotator cuff can lead to mechanical failures of the implant.

The reversal compensates for loss of rotator-cuff performance by idealizing deltoid tension and using the deltoid muscle to fill the biomechanical role of stabilizing the humeral head in the glenoid vault during arm elevation.

Absent deltoid tension, a deficient rotator cuff permits superior migration of the humeral head, which results in loss of a fulcrum and impairs the patient’s ability to elevate the humerus, Dr. Sperling explains.
a comprehensive approach to preoperative evaluation, operative decision-making and a postoperative program to manage pain and facilitate early motion for preventing stiffness. “Patients are moving the day after surgery,” Dr. Sperling says. “And the results have been very encouraging, with typical patients able to be discharged after one night in the hospital.”

By returning the patient home quickly to continue aftercare with his or her primary physician, Mayo orthopedists eliminate the expense and inconvenience of a follow-up visit to Mayo. “Most of my patients just send in follow-up films in six weeks, so it’s very efficient and convenient for the patient,” Dr. Sperling says.

**Patient Evaluation**

Despite the growing enthusiasm for RSA, as with any clinical decision this option has limits and is not for all arthroplasty patients. Optimal outcomes depend on a thorough patient workup that includes medical and lifestyle history, physician exam and imaging studies. Clinicians need to understand the patient’s activity level, occupation and expected functional demands placed on the shoulder, as well as look for evidence of pre-existing dysfunction. “RSA does offer real advantages in carefully selected patients,” Dr. Sperling notes. “But enthusiasm for using it needs to be tempered by considering each individual’s shoulder pathology.”

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**Figure 1.** Preoperative radiograph demonstrates severe glenoid bone loss.

**Figure 2.** Example of patient-specific instrumentation (PSI) made using a custom CT scan of the patient’s shoulder.

**Figure 3.** PSI helps the surgeon to decide intraoperatively between total shoulder arthroplasty and reverse arthroplasty.

**Figure 4.** Placement of the baseplate and the center screw.

**Figure 5.** Placement of the glenosphere.

**Figure 6.** Postoperative radiograph.
Mayo Clinic Approach to Complex Nonunion of Fractures

Trauma from high-energy impacts typical of motorcycle, car or snowmobiling accidents is a common cause of complex fractures that can lead to nonunions. Patients suffering from the pain and impaired function caused by nonhealing bones typically seek centers of orthopedic excellence such as Mayo Clinic to benefit from integrated, advanced, multidisciplinary team care to resolve the complex issue.

The Team Advantage

There are multiple reasons a fracture can fail to heal, according to William W. Cross III, M.D., Mayo Clinic orthopedic trauma surgeon. These include:

- metabolic and endocrine deficits
- poor bone quality at the fracture site
- presence of infection
- poor implant selection
- improper implant placement and fracture alignment
- errors in soft-tissue management

When implant fatigue outpaces bone growth, patients experience continued function and mobility problems and pain that can last months or even years. (See Patient Story.) Mayo Clinic’s deep clinical and surgical expertise, combined with an extensive specialty and subspecialty team approach, ensures the best individualized treatment options are available for each patient.

“I work very closely with interdisciplinary teams, and that expertise includes plastic and microvascular surgeons, radiologists, endocrinologists and more,” Dr. Cross says. “It’s this depth and breadth of specialties at Mayo that is key to our successful track record of resolving these issues for each patient’s unique situation.”

For example, if team members suspect infection is impairing healing, they can obtain infection labs and aspirations to evaluate nonunion sites—typically at the initial visit. Other labs are performed when metabolic or hormonal disorder involvement is suspected, such as a parathyroid hormone or vitamin D deficiencies.

Importantly, Dr. Cross’s team collaborates with endocrinology colleagues while the patient is still in the clinic. Cases with compromised soft tissues benefit from real-time consultation with plastic surgery specialists who can offer various muscle flaps to provide beneficial tissue coverage. In cases that require aspiration or biopsy around complex anatomy, such as the pelvic area, Dr. Cross has the expert help of Mayo’s interventional radiology team.

Options to Optimize Healing

Typical nonunion treatment strategies include: Figure 1a. 69-year-old female referred to Mayo Clinic with severe pain in her left hip eight months after medullary nailing for an atypical subtrochanteric femur fracture. Figure 1b. After negative infection and endocrine evaluations, revision surgery included rigid fixation with maximal compression, correction of her mechanical axis and adding biology (autograft) to the nonunion site.

1. **Improving stability.** Revision surgery to optimize placement and function of implants can stabilize them in an enhanced biomechanical setting.
2. **Realigning fractures.** Changing the biomechanics of the fracture through realignment can induce bone growth and healing in cases where malalignment impeded it.
3. **Adding biological adjuncts.** Deficient healing environments can be improved to get the bone to heal through means such as autografting, adding orthobiologic agents that stimulate healing and correction of metabolic disorders that impair bone growth, such as the most common diagnosis: vitamin D deficiency.

Says Dr. Cross: “With Mayo’s team approach, everybody is a pager call away. That means that with my patient in the room next to me, I can simply page my colleagues and review the case in real time utilizing our integrated electronic imaging and medical record system. Getting this all organized and taking care of it all in the same day or even hour really benefits the patients. They deeply appreciate not having to wait until their next visit to get an answer.”
Patient Perspective

Back on the Bike: Subtrochanteric Femur Fracture Repair Resolves Popped Rod, Restores Stability for Active South Dakota Patient

For chiropractor Jeffrey Hock, D.C., 39, the eight-hour drive from his home in Rapid City, South Dakota, to Mayo Clinic in Rochester, Minnesota, is “a drive well worth it.”

“I tell you what: Just do it, make the trip to Mayo to have the highest confidence that you will get all the expert, comprehensive care and resources needed,” he says now.

First Repair
It has been four years since Dr. Hock had the mountain bike accident on a remote Black Hills trail in which he sustained a complex right subtrochanteric femur fracture. Carried out of the backwoods on a wheeled gurney because the trail was impassable to vehicles, Dr. Hock was originally treated locally with open reduction, cerclage wiring and medullary nailing in June 2010. Unfortunately, that failed four months postoperatively, in September. (Figure 1a & 1b) The titanium rod stabilizing his femur popped while he stood briefly on the unsupported repaired leg to put his pants on. He was revised locally to a stiff plate construct.

Revision
Once cleared for full weight-bearing activity, Dr. Hock traveled in spring 2011 to Florida on vacation. As he walked through the airport “the bone shifted and the plate broke,” he recalls. He finished his vacation hobbling with a cane, returned home and learned it would be two weeks before he could have a third surgery. That’s when he called a friend who had recommended Mayo Clinic, and got an appointment the next week with orthopedic surgeon and trauma specialist William W. Cross III, M.D.

Mayo Clinic Solution
“After a negative evaluation for both infection and endocrine abnormalities, Dr. Hock was revised with a blade plate. This allowed us to optimize his mechanical axis for healing and provide maximal interfragmentary compression,” explains Dr. Cross. “We applied ipsilateral proximal tibia bone graft to the nonunion site as well to further stimulate the healing environment. Final images at 2 ½ years from his initial injury show complete union and restoration of his high-level activities.”

Adds Dr. Hock: “The healing after the third surgery was much better. I was a little gun-shy after my first two experiences to try early physical therapy the third time around, but the Mayo team so clearly knew what they were doing that I quickly became confident that this was the path to the best recovery—and it has been.”

Back On the Bike
Dr. Hock still mountain bikes despite a significant psychological challenge to return to the sport he loves. “But I’m so glad I did,” he says. “And that I can.”

Figure 1A. Injury film demonstrating the complex right subtrochanteric femur fracture.

Figure 1B. The fracture was initially treated with a medullary nail and open reduction with a proximal cerclage cable.

Figure 1C. Nonunion and implant failure occurred four months postoperatively.

Figure 2A. Nonunion six months after subsequent revision with a stiff plate construct.

Figure 2B. Final radiographs 2 ½ years after initial injury. Principles of optimizing the mechanical axis, compression, and bone grafting were utilized.
Continuing Medical Education Opportunities

9th Annual Mayo Clinic Spine Center: Medical and Surgical Spine Course
Jan. 15-17, 2015—Mayo Clinic Education Center, Phoenix, Arizona

This course offers a rewarding clinical training experience for all spine care practitioners, including spine surgeons, medical specialists, primary care providers and family medicine providers, as well as physical therapists, clinical nurse practitioners and physician assistants. Over three days of engaging teaching, faculty focus on current and emerging spine topics that are driving national changes in the quality and delivery of care. Attendees will learn new skills to survive in the emerging spine care environment through a unique split curriculum for both nonoperative and procedural specialists. The expert Mayo Clinic faculty offer updates via didactics, case presentations, a hands-on examination skills lab, an ultrasound-guided injection skill lab and surgical skill labs.

Contact: Call 800-323-2688 (toll-free) or email cme@mayo.edu

New Techniques in Shoulder Arthroscopy, Arthroplasty and Fractures
May 1-2, 2015—Mayo Clinic, Rochester, Minnesota

An advanced course for orthopedic surgeons treating disorders of the shoulder, this offering includes didactic sessions and laboratory experience using cadaver specimens. Live video demonstrations and panel discussion are an integral part of the overall learning experience. This course teaches the principles and techniques for management of rotator cuff tears, SLAP lesions, instability and arthritis.

Contact: Call 800-323-2688 (toll-free) or email cme@mayo.edu

Mayo Clinic Sports Medicine Center
Rochester Site Expanded, Minneapolis Site
Opened Fall 2014

Mayo Clinic Sports Medicine Center offers advanced, comprehensive care and state-of-the-art sports medicine, training and performance-enhancement facilities in two Minnesota locations. The new downtown Minneapolis site at Mayo Clinic Square opened Oct. 1, 2014, and Rochester offerings have expanded at the Dan Abraham Healthy Living Center (Figure 1).

With a proven commitment to patient-focused care, Mayo Clinic’s interdisciplinary sports medicine practice is designed to meet the needs of all athletes and individuals over a range of ages. Our patients include those performing at, or aspiring to, an elite and professional level; weekend warriors and youth who are looking to improve performance and prevent injury; those seeking rehabilitation and relief from joint and muscle pain, or to recover from deconditioning.

Patients do not need to be existing Mayo Clinic patients to receive care at our Sports Medicine Center. Walk-in appointments are welcome and accommodated whenever possible.

Contact Us
To schedule an appointment at Mayo Clinic Sports Medicine Center, please call 1-507-266-9100 for our location in Rochester, Minnesota or 1-612-313-0520 for our location in Minneapolis, Minnesota. Online, visit: https://sportsmedicine.mayoclinic.org

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