Preoperative Planning and Patient-Specific Instrumentation Improve Accuracy of Shoulder Arthroplasty

Total shoulder replacement has clinical efficacy for the treatment of primary and secondary degenerative conditions of the shoulder. It has excellent surgical outcomes, providing long-term pain relief and improved function for the majority of patients. It is also a demanding procedure, with known complications. Failure of the glenoid component of the implant is one of the most common and worrisome complications in the mid to long term.

Glenoid component failure can result from anatomic factors such as glenoid version or rotator cuff insufficiency, from fixation problems, or from the component itself — for example, metal-backed versus cemented polyethylene glenoids. Inaccurate component positioning is also a critical factor in long-term implant survival; improperly placed implants increase the risk of instability, wear and loosening and the need for revision surgery, which is typically more challenging and less successful than the primary operation.

Proper glenoid placement in terms of version and inclination is difficult, however, especially in the presence of complex and irregular patterns of glenoid bone loss with unreliable landmarks. When reverse arthroplasty is performed in these cases, directing the glenoid baseplate along an axis with enough bone stock for fixation can be a daunting task.

Joaquin Sanchez-Sotelo, M.D., Ph.D., an orthopedic surgeon specializing in shoulder and elbow surgery at Mayo Clinic’s campus in Rochester, Minnesota, observes that the classic method of using standard X-rays to estimate areas of missing bone and guide placement of the component in space is imperfect.

“We are often able to get it right, but sometimes the amount of bone loss is so abnormal that it is very difficult,” he says. “Fortunately, three developments in the last few years — 3-D preoperative planning, patient-specific instrumentation and 3-D printing — have greatly increased the accuracy of glenoid component placement and improved the likelihood of optimal outcomes in complicated cases.”

Preoperative planning
Three-D computer planning for implant placement originated with early studies investigating whether 3-D imaging helped surgeons better identify glenoid bone loss. In the current process, two-dimensional CT images of a patient’s scapula and humerus are uploaded into a software system, which reformats them into accurate 3-D models. This allows far better visualization of the glenoid cavity than conventional X-rays or two-dimensional CT. It also allows surgeons to clearly visualize and consider preservation of support bone, implant version and inclination angle, and glenoid contact for each patient.

A large body of research has demonstrated improved glenoid orientation with the use of preplanning software; most studies demonstrate...
average derivations in version and inclination of 5 degrees or less from the intended component position.

John W. Sperling, M.D., an orthopedic surgeon specializing in shoulder surgery at Mayo Clinic’s campus in Rochester, Minnesota, notes the large volume of complex cases seen at Mayo Clinic has helped drive innovation in this space. “This is an extremely powerful tool because it allows movement of the component to show varying degrees of orientation. It is especially helpful in cases with marked distortion of anatomy and significant bone loss,” he says. “In the four years we have been helping develop this technology at Mayo Clinic, the degree of sophistication has increased substantially, so we can now plan the surgery completely on the computer before entering the operating room.”

### Patient-specific instrumentation

Patient-specific instrumentation (PSI) allows surgical implementation of the preoperative plan through the use of patient-specific guides that direct glenoid implant placement and fixation, including positioning and orientation of the implant, the reaming depth and angle, and the trajectory of drilling for screw placement. Several vendors offer patient-specific instrumentation, and the types of instruments vary considerably, including pin guides versus cutting guides, a greater or lesser degree of surgeon input in the preplanning process, and various types of imaging for the 3-D model. It is unclear whether any is superior, and the choice depends mainly on cost and physician preference (Figure 1, see page 1).

Many groups have reported on the use of patient-specific instrumentation for shoulder arthroplasty, with generally positive results. A randomized controlled trial published in the December 2012 edition of *The Journal of Bone & Joint Surgery, American Volume*, compared patient-specific instrumentation with standard instrumentation for glenoid placement. Overall, the PSI group had fewer incorrectly positioned glenoid components and significant improvement in the selection and use of the appropriate implant for patient anatomy (Figures 2, 3 and 4).

### 3-D printing

3-D printers use computer software to create physical objects from CT data. In the last decade, technological advances have lowered the cost of 3-D printers, thereby expanding their use. Custom 3-D-printed implants have been used in femoral and tibial hemiarthroplasty, and in 2015, surgeons at Mayo Clinic’s campus in Arizona performed bilateral total hip arthroplasty using 3-D-printed implants for a patient with a bone growth disorder who was too small for conventional hip implants. “Mayo Clinic owns 3-D printers, so we can print the bones of the most complicated cases in-house in a day,” Dr. Sanchez-Sotelo says (Figures 5 and 6). “It’s very powerful to have a printed replica of the bone in your hands outside the body while performing the procedure.”

![Figure 2. Patient-specific instrumentation for placing the shoulder arthroplasty.](image)
Figure 3. Instrumentation helps direct the guidewire in the correct version and inclination.

Figure 4. Patient undergoes placement of a short stem uncemented reverse arthroplasty.

Figure 5. Three-D printed scapula.

Figure 6. Three-D printed shoulder.

**Long-term outlook**

Computer planning programs and patient-specific instrumentation appear to increase accuracy and efficiency, minimize outliers, and slightly lower operative time and costs. But they have not been proved to be cost-effective and whether the added cost is clinically beneficial in the long-term is a matter of debate.

Dr. Sperling says computer planning and PSI are generally reserved for patients with complex anatomy, including dysplasia, bone deficiency or deformity secondary to prior trauma.

“We perform more shoulder replacement surgeries than any other center in the United States and are a leader in patient-specific instrumentation for shoulder arthroplasty. In part that is because we have been a pioneer in helping develop PSI techniques and in part because we see many complex cases. For those patients, we have all the tools needed to ensure a successful surgical outcome and implant durability,” he says.

**For more information**


Distal Radius Fractures in Older Versus Younger Patients

Fractures of the distal radius are among the most common injuries seen in an adult orthopedic practice and account for about one-sixth of fractures treated in emergency departments. Most result from a fall on an outstretched hand with the wrist in extension. The fractures occur primarily in young adults and people over age 65, and can vary considerably between the two groups.

In young people, for example, distal radius fractures are often caused by high-energy trauma that involves various combinations of bending, compression, impaction and shearing. These injuries may result in fractures with metaphyseal comminution, and can, in some cases, cause extensive damage to the joint surface, fragmentation of the metaphysis, and injury to the ulna and triangular fibrocartilage. In older adults, a large majority of distal radius fractures result from lower energy injuries such as ground-level falls, often leading to more typical extra-articular, dorsally angulated or displaced fractures.

The various fracture patterns and displacement of the fragments can provide a sense of fracture stability; closed reduction and immobilization are then used to help determine treatment. Radiographs are compared before and after reduction to assess for acceptable alignment in the cast or splint, and additional imaging, such as CT, may be used to look for other problems, such as carpal bone injury.

Although surgery is often considered for displaced and unstable distal radius fractures, optimal treatment depends on several factors, according to David G. Dennison, M.D., a hand and wrist surgeon at Mayo Clinic’s campus in Rochester, Minnesota.

“The goal of treatment is to restore the previous level of function, but the appropriate treatment may vary, depending upon the patient’s age and activity level, existing medical conditions, bone quality, and amount of displacement,” he says. “All of these factors need to be carefully considered and individualized in order to achieve the best functional outcome while also minimizing risk. In general, less invasive treatments that achieve satisfactory alignment and stable reduction of the bone fragments can lead to good outcomes.”

Treatment options

For older, less active patients and adults with low or moderate demands, closed reduction and casting are almost always preferred, especially for mild shortening of 2 to 3 millimeters (mm) and articular displacement of less than 2 mm, Dr. Dennison says.

“You have to consider a patient’s activity level. With young patients, we tend to be more aggressive in achieving a more anatomic reduction of the fracture and the joint surface. Many older adults are now remaining more physically active, and they also may benefit from surgical treatment of a displaced or unstable fracture. On the other hand, some older and low-demand patients may accept a mild or moderate deformity with acceptable function following fracture healing. Surgical treatment is considered if closed reduction with splinting does not result in acceptable alignment.”

Volar plate fixation

One common method of treating extra-articular fractures is to obtain an open reduction and then apply external fixation using a volar locking plate. Although volar plates are not applicable to all fractures, the literature increasingly supports volar plate fixation with distal locking screws or pegs for older patients, including those with osteoporosis.

The volar approach commonly used today involves a longitudinal excision over the flexor carpi radialis tendon and takes advantage of an anatomic recess at the pronator quadratus fossa for plate placement. In intra-articular fractures, the exposure may include release of the brachioradialis tendon to expose the fracture site and allow access to the subchondral bone and to release the deforming force from the brachioradialis. The process then continues with reduction of the volar lunate facet, the dorsal lunate facet and the radial styloid. If needed, a dorsal arthrotomy or arthroscopy is used to obtain reduction of the joint surface.

Volar plate fixation has proved superior to external fixation in terms of recovery and minor complications, but studies have not shown that it improves long-term overall function. It also can result in complications that require revision surgeries, such as tendon rupture. Other limitations of volar plating include the inability to visualize the joint surface or interosseous ligament injuries and difficulty in stabilizing distal and ulnar-sided radius fracture fragments.

“Mayo Clinic has extensive experience with the volar approach, and we are leaning toward internal fixation more than in the past because we have better locking plates that can stabilize the fracture from the palmar side of the wrist,”
Innovative Approaches Improve Limb Salvage in Pediatric Patients With Cancer

Osteosarcoma and Ewing’s sarcoma are the most common primary bone cancers in children and young adults, with a peak incidence in patients ages 10 to 25. These cancers primarily affect the metaphyseal portions of the bone in the hip and knee and because they are aggressive, amputation was long considered the only way to achieve local control of the tumor. Yet for decades, survival remained dismal — around 10 to 20 percent — even after amputation.

Today, the five-year survival rate for local pediatric bone cancers is 60 to 80 percent — a dramatic improvement since the 1970s, according to Peter S. Rose, M.D., a oncologic orthopedic surgeon at Mayo Clinic’s campus in Rochester, Minnesota.

“Several simultaneous developments completely changed the outlook for these patients,” he says. “Adjuvant chemotherapy regimens allowed better local and systemic control, improved imaging with CT and MRI allowed surgeons to more accurately assess the extent of the tumor and plan resection, and the development of custom implants opened the possibility of reconstruction instead of amputation, which was traditionally the treatment of choice. At one time, many surgeons believed limb salvage wasn’t a viable option, but now limb-salvage techniques are the standard of care for most tumors.”

Long-term studies dating back 30 years, including those at Mayo Clinic, have shown that limb-sparing operations performed with wide margins and chemotherapy do not compromise survival and, because techniques for limb salvage have improved significantly in the last few decades, oncological results are now comparable to amputation.

A Mayo Clinic study published in The Journal of Surgical Oncology in 2016 reviewed 204 adult patients who underwent endoprosthesis for a malignancy of the proximal femur. Following the procedure, the mean Harris Hip and Musculoskeletal Tumor Society scores were 75 and 18, respectively. Five-year survival was 54 percent for patients with primary disease.

Surgical management in skeletally immature children

Reconstruction after resection of the proximal femur in children presents a special challenge for surgeons, however. After salvage, the limb should have an acceptable degree of function and cosmetic appearance and should be capable of withstanding the demands of normal daily activity as well as or better than an artificial limb. But the prostheses typically used to achieve these aims in older teens and adults are unsatisfactory for skeletally immature children undergoing resection of the entire distal or proximal portion of the bone. Removal of the growth plate creates the potential for leg-length inequality in.

For more information

the contralateral limb, which continues to grow normally at a rate of about 1.6 centimeters a year. The younger the child when diagnosed with bone cancer, the greater the potential discrepancy at skeletal maturity.

Limb-length inequalities have profound functional and cosmetic consequences for young patients. Expandable implants that can be lengthened periodically were developed in the 1970s to address these issues.

The first generation of these implants had a worm gear mechanism that allowed a telescoping cylinder to increase the length by turning a screw through a small surgical incision. This had to be done repeatedly to keep pace with growth on the contralateral side and therefore required multiple surgical procedures with associated pain, rehabilitation time and infection risks.

The new generation of expandable prostheses solves these problems by using stored energy inside the implant that is activated noninvasively with a magnet outside the body. This allows controlled expansion without the need for surgery. Studies indicate little difference in cosmesis and function between traditional modular and noninvasive expandable implants. Both, however, have a high complication rate as well as bone loss around the stem of the prosthesis that may limit future revision options.

“With the expandability and flexibility come problems with durability,” Dr. Rose says. “An endoprosthesis in a child will eventually need to be converted to an adult implant, and even implants in young adults will wear out in a few years, mainly due to infection and mechanical or fixation failure. All are difficult issues and some may overlap, but a discrete and frequent problem is how to obtain fixation in the bone when revisions are needed. Patients are already missing a large amount of bone due to cancer, so when a prosthesis wears out and further damages the bone, how do we adjust for that?”

Compressive fixation
One answer is self-adjusting compressive fixation, a relatively new limb-salvage technology that uses compression, via a traction bar, to stimulate osteointegration and provide fixation for short end segments after bone or tumor resection. It differs from traditional stemmed prostheses in that it requires only 4 to 8 centimeters of residual bone for fixation.

A study published in Clinical Orthopaedics and Related Research in February 2016, retrospectively reviewed 27 patients who underwent distal femoral reconstructions with the prosthesis over a 13-year period. The authors reported an 11 percent failure rate at 10 years.

Christopher P. Beauchamp, M.D., an orthopedic surgeon at Mayo Clinic’s campus in Arizona, has been one of the pioneers in using compressive fixation and says it is an important option that can be incorporated into pediatric reconstructions. Still, prostheses eventually wear out.

“It’s fair to say that over time, there is the expectation that all implants in children will wear out, but we hope to get 10 years of good solid function, and that is a great result,” Dr. Rose says. “We have achieved this here at Mayo Clinic by adapting technologies and techniques from hip and knee replacements and revisions and using them in new ways for patients with cancer. This has been possible because of the collaborative work among cancer surgeons and orthopedic surgeons, including those who specialize in complex hip and knee replacement.”

For more information

Zimel MN, et al. Revision distal femoral arthroplasty with the Compress prosthesis has a low rate of mechanical failure at 10 years. Clinical Orthopaedics and Related Research. 2016;474:528.

Trauma Surgeons Uniquely Qualified to Treat SIJ Dysfunction

The sacroiliac joint (SIJ) is a diarthrodial joint stabilized by bony ridges on the articular surface of the sacrum that articulate with reciprocal surfaces on the ilium. An associated network of supporting ligaments also helps stabilize the joint. The anterior sacroiliac ligaments resist external rotation of the ilium relative to the sacrum; the posterior sacroiliac ligaments, which resist both internal rotation and vertical displacement, are essential for stabilizing the pelvic ring. Degeneration or injury to any aspect of the joint, including the ligament complex, can...
lead to pain in the low back and sometimes the buttock or proximal thigh.

The SIJ was first identified as a source of back pain at the beginning of the 20th century but was subsequently ignored for decades. It has recently re-emerged as a known pain generator, although it remains underrecognized and under-diagnosed. The current literature suggests SIJ involvement in 15 to 30 percent of patients presenting with low back pain. Some studies report a much higher prevalence — up to 61 percent — in patients who have undergone lumbar fusion procedures, whether or not the fusion involves the sacrum.

High-energy trauma, such as motor vehicle crashes and falls, is responsible for a significant number of SIJ injuries. Repetitive trauma, inflammatory arthritis, osteoarthritis, joint hypermobility — especially during pregnancy — and degeneration of the joint also can cause SIJ pain.

**Diagnosis**

Patients with SIJ disorders typically present with burning, stabbing pain below the L5 vertebral level that may or may not radiate to the buttocks and thigh. About 28 percent have pain that radiates to the knee. Unlike discogenic pain, which usually worsens with sitting, SIJ symptoms are more likely to be worse in transitional movements, such as rising from a chair. Still, the discomfort can often be confused with radicular or discogenic pain. Diagnosis is further complicated because SIJ problems can co-occur with degenerative disk disease, arthritis or sciatica.

In the absence of acute trauma, diagnosis involves a careful combination of clinical history, physical exam, pain provocation tests and image-guided intra-articular anesthetic injections to confirm the diagnosis. William W. Cross III, M.D., an orthopedic trauma surgeon at Mayo Clinic’s campus in Rochester, Minnesota, says a different or an additional pain generator may be involved if patients don’t experience significant relief from diagnostic injections.

Early imaging is discouraged; SIJ changes are unlikely to show up on radiographs, and decades of research have shown that early imaging not only fails to improve outcomes in patients with low back pain but also can often lead to unnecessary testing and more-aggressive treatment.

**Conservative management**

Initial treatment for SIJ pain is conservative. It includes measures such as physical therapy, exercise, weight loss, nonsteroidal anti-inflammatory drugs, intra-articular steroid injections, and sometimes SIJ manipulation, massage, or a belt to compress and support the joint. Carefully selected patients who fail a six- to 12-month trial of these measures may be candidates for radiofrequency denervation procedures, which are associated with relief of SIJ pain. The duration of the relief is unknown, however, and some results have been difficult to reproduce.

SIJ arthrodesis may be considered for recalcitrant SIJ pain that has failed all other treatment options. The indications for performing the surgery are complex and depend on individual patient factors. Dr. Cross says his group is currently collecting data to identify the patients most likely to benefit from surgical intervention.

**Surgical management**

Fusion of the SIJ is defined as the presence of a continuous segment of solid bridging bone that extends from the sacrum to the ilium. Most fusions are currently performed using minimally invasive techniques that require a small lateral incision in the buttocks near the posterior iliac spine. In this approach, the fascia is dissected to reach the outer table of the ilium, and a hand drill is used to create a pathway across the ilium and SI joint into the sacrum. Bony surfaces are debrided and decorticated with a deployable curet system, after which the debris is removed with irrigation. An autologous bone graft and bone graft extender are then percutaneously placed into the SIJ. An implant matched to the patient’s anatomy is placed across the joint under fluoroscopic guidance to fully compress and stabilize the joint. In some cases, a second implant — an anti-rotation screw — may be used to enhance joint stability.

Many limitations of open surgery — relatively large incisions, significant bone harvesting, postoperative pain, and a lengthy hospital stay and postoperative recovery — may be eliminated with minimally invasive techniques.

“What sets this approach apart is that patients may have significant pain relief on day one,” Dr. Cross says. “They walk with crutches or a walker for one to two weeks and are able to advance weight bearing as tolerated, whereas with open surgery, some patients may be kept in the hospital for several days and are non-weight-bearing for one to two months.”

According to short-term data, some of which was obtained at Mayo Clinic, pain relief is durable for two years post-surgery; extended data collection is expected to show continued positive outcomes.

“Our goal is 100 percent return of quality of life,” Dr. Cross says. “If people want to go back to playing tennis, they can do that. The SI joint only has one to two degrees of motion at most, so loss of motion is minimal. Furthermore, patients...
benefit greatly from our multimodal program that includes orthopedic surgeons, physiatrists, pain medicine specialists, physical and occupational therapists, and specialists in complementary medicine, such as acupuncture and biofeedback.”

Dr. Cross says another unique advantage at Mayo Clinic’s Rochester campus is that SIJ surgery is performed by a traumatologist, who has a unique background in iliosacral anatomy and a particular understanding of post-traumatic changes in the joint.

“I am a great proponent of trauma surgeons becoming involved in the management of chronic pathology of the SI joint because we have a unique ability to care for these patients and their complex anatomy. Here at Mayo, this has blossomed into a significant subspecialty practice,” he says.

“The ability to help these patients with their chronic pain and return a meaningful quality of life to them is the greatest feeling.”

Education Opportunities

For more information or to register for courses, visit https://ce.mayo.edu/orthopedic-surgery/orthosurgery, call 800-323-2688 (toll-free) or email cme@mayo.edu.

Advances in Brachial Plexus Reconstruction: A Surgical Skills Course 2017
April 13-15, 2017, in Rochester, Minn.
This course provides an update on adult and pediatric brachial plexus reconstructive surgery, including brachial plexus injuries, surgical planning, supra and infraclavicular exploration, various nerve transfers and grafting, secondary surgical reconstructions, and obtaining grasp and management of pain.

Knee Dislocation and Multiple Ligament Reconstruction 2017
May 11-12, 2017, in Rochester, Minn.
Designed for high-level arthroscopists, this course focuses on current techniques for multiligament knee reconstruction, including anterior cruciate ligament, posterior cruciate ligament, medial collateral ligament-posteromedial corner and fibular collateral ligament-posterolateral corner surgical techniques.