Many areas of surgery have been revolutionized by the development of minimally invasive surgical (MIS) procedures enabled by the introduction of fiberoptic technology (i.e. arthroscopy, endoscopy, laparoscopy, etc.). The clinical benefits to patients are profound when an “open” procedure can be made minimally or less invasive. By definition, performing any procedure less invasively results in less soft-tissue and bone disruption, which reduces pain, speeds healing and the recovery of patients, and potentially reduces complications. However, there are also new challenges that surgeons face when trying to develop techniques that are minimally invasive. For instance, if a less invasive technique limits the surgeon’s ability to achieve the surgical goal, then the procedure cannot be considered a success. In addition, if the surgeon’s view of the work area is limited, then the procedure could potentially be less accurate or damage surrounding structures, which would also result in a less than optimal outcome for the patient.

Compared to other surgical disciplines, adult reconstructive orthopedic surgery has fallen behind the trend to make procedures minimally invasive because of several unique challenges. For example, in the area of total joint-replacement (TJR) surgery, surgeons focus on both bone and joint surfaces. However, many of the complications that develop during or following surgery are directly related to the way surgeons handle the soft tissues, rather than the bone. The current techniques require extensive soft-tissue dissections to accurately prepare the bone and insert the implant. In addition, the tools that surgeons use to plan and execute TJR have not significantly changed in over 30 years of joint-replacement surgery.

There are many inherent benefits of developing MIS techniques for TJR, including: reduced soft-tissue and bone dissections, less bleeding, fewer infections and dislocations, less damage to surrounding muscles, ligaments, nerves or blood vessels, less pain and a faster recovery for the patient. There will also be less disruption of the blood supply to bone and surrounding soft tissues, resulting in better overall healing, which will be especially important as we develop new biologic based tissue-engineered joint-replacement surfaces.

The surgical goals in joint reconstruction procedures and TJR are to relieve pain by reconstructing or replacing the diseased joint surfaces with a new surface. Currently, we use man-made artificial replacement surfaces. In the future, though, surgeons will likely be able to replace a damaged surface with a tissue-engineered composite graft, consisting of bone and cartilage grown in vitro from the patient’s own tissues. Key to the success of any reconstructive joint surgery, whether using man-made or biologic materials, is to obtain an accurate fit and fixation of the implants to the prepared surfaces and to achieve good overall limb alignment. In addition, the interaction between the bones and soft tissues like ligaments, muscles and capsular restraints is another large contributor to the functioning of the joint after reconstruction. Adding to the challenge, both natural and reconstructed joints are subjected to extremely large forces requiring relatively rigid implants of significant bulk, making introduction of the artificial or biologic component in a less invasive way difficult. Satisfying these requirements – proper fixation, joint alignment, and soft-tissue balancing – is critical to the successful...
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performance of the reconstructed joint and positive patient outcomes.

Because of these challenges, current surgical exposures are large and require extensive soft-tissue dissections to access, visualize and prepare the bone surfaces for implantation and to insert the new artificial joint surface. Surgeons and clinical researchers also lack sensitive measurement devices that can be used both during surgery and post-operatively to accurately gauge factors like alignment, soft-tissue balancing, load transfer, implant wear, loosening or implant migration.

In general, there are three main components of most adult reconstructive surgical procedures: bone preparation, soft-tissue balancing, and the insertion and fixation of the new (artificial or biologic) surface. Adult reconstructive surgeons undertake several interdependent and sequential tasks in order to achieve the surgical goals:

- Soft-tissue dissection and surgical exposure in order to visualize the bone and joint surfaces to be reconstructed.
- Evaluate interaction of bone and soft-tissue constraints (ligaments, capsular, muscular).
- Preparation and shaping of the bone surface.
- Insertion and fixation of the implant or resurfacing material.
- Evaluation of composite bone/implant/soft-tissue system (range of motion, balancing, stability, etc.).
- Closure and repair of the surgically altered soft tissues.
- Post-operative follow up and evaluations.

By addressing each of these steps, we can identify several clinical and technical challenges to overcome in order to perform truly minimally invasive joint-reconstructive surgery and provide the post-operative tools to gauge and quantify surgical outcomes. For instance, on the purely clinical side, minimally invasive procedures should utilize surgical exposures that reduce the trauma on the patient’s soft tissue and bone, not only the incision length, which could reduce rehabilitation time for the patient. CAOS, though, can help improve surgical performance in all these areas.

Advanced visualization methods that allow surgeons to view models of the underlying anatomy through the skin have been developed (Fig. 10.1), and are being improved upon. CAOS systems, such as surgical navigation tools, can assist in the evaluation of the interaction between bone and soft tissue through a combination of tracking of the patient’s pre- and intra-operative motion and prediction based on biomechanical models of the patient’s anatomy. Tracking and displaying the patient’s actual motion, and simulating possible outcomes based on surgical plans can improve the surgeon’s understanding of the surgical outcome (Fig. 10.2). This can improve prediction accuracy.

Fig. 10.1. Advanced visualization with Image Overlay, where virtual models are overlaid onto patient anatomy

Fig. 10.2. Prediction of post-operative outcome for total hip arthroplasty
compared to models solely based on pre-operative images, due to additional information and constraints introduced by tracking patient motion. Evaluation of the patient’s motion can be used pre-operatively, intra-operatively, and post-operatively to accurately characterize the patient’s biomechanics. Navigation systems to assist the surgeon in accurately locating and placing cutting tools, cutting guides, and implants are already available commercially. More advanced robotic or semi-active devices which will help the surgeon cut more precisely (Fig. 10.3), and to actually cut the implant cavity directly with a small robotic platform (Fig. 10.4), are currently being developed. These small active and semi-active robotic systems will help motivate the development of smaller implant components that conform more closely to the natural anatomical shape, rather than the large bulky implants currently in use designed to be inserted onto flat surfaces. Post-operative follow-up is also being improved with CAOS tools, allowing accurate determination of implant component positions from a standard post-operative radiograph (Fig. 10.5).

In order to perform less or minimally invasive surgery, adult reconstructive surgeons will need to perform more accurate and precise pre-operative planning coupled with simulations of their actions before the actual patient’s surgery. Surgical techniques will need to be radically modified. Technically, less invasive surgical tools and more powerful intra-operative visualization devices that can provide updated images of the bone surfaces and soft tissues being manipulated in a less invasive way are needed. These tools also require high fidelity and accurate pre-operative planners and surgical

Fig. 10.3. Precision Freehand Sculptor (PFS) that only cuts in areas with tissue to be removed

Fig. 10.4. Miniature Bone-Attached Robotic System (MBARS) that directly attaches to the bone before milling the implant cavity

Fig. 10.5. Accurate evaluation of post-operative radiograph using Xalign
simulators. Then, in order to address the wide spectrum of clinical challenges faced by surgeons, various enabling technologies will need to be integrated into a complete MIS system (Fig. 10.6). This next generation of tools will include surgical planners and simulators, image-guided navigation systems, image overlay visualization, micro-electromechanical systems (MEMS) sensors and actuators, micromanipulators and other robotic surgical devices.

Fig. 10.6. Next-generation CAOS/MIS surgical tool suite