

MIS Meets CAOS™ – Less and Minimally Invasive Joint Reconstruction

a report by

Dr Anthony M DiGioia III, Dr Branislav Jaramaz and Paula Deasy

Institute for Computer Assisted Orthopaedic Surgery (ICAOS), Western Pennsylvania Hospital

Dr Anthony M DiGioia III is a practicing orthopaedic surgeon and the director of the Institute for Computer Assisted Orthopaedic Surgery (ICAOS) at the Western Pennsylvania Hospital. He was recently appointed Chief of the Division of Orthopaedic Surgery at the Western Pennsylvania Hospital and also serves as the medical director of the T9 Orthopaedic Unit. Dr DiGioia is a senior research scientist, founder and co-director of the Center for Medical Robotics and Computer Assisted Surgery at Carnegie Mellon University. He received a BSc and MSc degree in Civil and Biomedical Engineering from Carnegie Mellon University and graduated with honors in a special field from Harvard Medical School.

Dr Branislav Jaramaz is Scientific Director of ICAOS at the Western Pennsylvania Hospital. He is also a research scientist for the Robotics Institute at Carnegie Mellon University and a co-founder of CASurgica, Inc. His professional and research interests are in computer-assisted surgery, including development of surgical systems and applications, pre-operative surgical simulation, medical image processing and computing and novel devices. Dr Jaramaz received his PhD in Civil Engineering/Computational Mechanics from Carnegie Mellon University.

Paula Deasy is a program officer and secretary for the AMD3 Education and Research Foundation and a co-director of the "MIS meets CAOS" symposium series. She comes to the foundation after working at Carnegie Mellon University. Ms Deasy received her BS in Industrial Management from Carnegie Mellon University and her MEd and MBA from the University of Pittsburgh.

Introduction

There have been many initiatives that are bringing less and minimally invasive surgical (L/MIS) techniques and computer-assisted orthopaedic surgical (CAOS) tools from the drawing board all the way through clinical testing, commercial development and now more routine clinical use. In many sites, MIS techniques and CAOS tools are being used on a routine basis. The American Academy of Orthopaedic Surgeons (AAOS) reported recently that computer-assisted systems are likely to become widely available to surgeons and will enable the delivery of biological and tissue-engineered therapies. Thanks to CAOS, important information will be available to surgeons when and where it is needed the most: before and during surgery.

These clinical and technological developments hold the promise to change the way that adult reconstructive surgery is performed and may improve patient outcomes dramatically. Recent developments of new surgical techniques, improved implant designs, use of navigation systems and mechanical tool redesign are now enabling L/MIS for partial and total joint arthroplasty.

Background and Significance

Many areas of surgery have been revolutionised by the development of MIS procedures developed after the introduction of fibre optic tools (i.e. arthroscopy, endoscopy and laparoscopy, etc.). The clinical benefits to patients are profound when an 'open' procedure can be made minimally invasive. By definition, performing any procedure less invasively results in less soft tissue disruption, which reduces pain, speeds healing and recovery of patients and potentially reduces complications.

Through the application of state-of-the-art surgical navigation tools, three-dimensional (3-D) medical imaging and computer-assisted surgical planning techniques, joint replacement surgery has the potential to achieve optimal results less invasively. The incisions required for procedures such as total

hip and total knee replacement are routinely less than half the size of those made using conventional techniques. Less invasive approaches mean far less soft tissue disruption and can lead to substantially better patient outcomes. 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 could potentially be less accurate in alignment or may damage surrounding structures, which would also result in a less than optimal outcome for the patient. In addition, there will likely be a steep 'learning curve' in the adoption of these newer L/MIS techniques. Therefore, the education of the practising orthopaedic surgeon on the next generation of surgical techniques will become very important.

Clinical Benefits

Compared with other surgical disciplines, adult reconstructive orthopaedic surgery had fallen behind the trend to make procedures less and minimally invasive because of several unique challenges. For example, in the area of total joint replacement (TJR) surgery, surgeons must focus on preparing bone and joint surfaces and not just the soft tissues as in other areas of surgery. Tissue is reconstructed and not just removed. 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. Traditional techniques require extensive soft tissue dissections to prepare the bone accurately and insert the implant and fix it to bone. The tools that surgeons use to plan and perform TJR have not changed significantly in over 30 years of joint replacement surgery.

There are many intuitive benefits of developing L/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.

Surgical Goals

The surgical goals in joint reconstruction procedures are to relieve pain by reconstructing or replacing the arthritic joint surface with a new surface. Currently, we use man-made artificial replacement surfaces. Keys to the success of any reconstructive joint surgery are to obtain an accurate fit and fixation of the implants to the prepared surface of bone and good overall limb alignment. In addition, understanding the interaction between bone and ligaments, muscles and capsular restraints are also very important factors 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. Achieving these goals is critical to the successful performance of the reconstructed joint and patients' outcomes. In the future, surgeons will likely be able to replace a damaged surface with a tissue-engineered composite graft made up of the patient's own bone and cartilage grown *in vitro*.

Clinical and Technical Challenges for L/MIS – The Process for TJR

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

In general, there are two necessary aspects of most adult reconstructive surgical procedures: bone preparation 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 these surgical goals:

- evaluation of bone and soft tissue constraints (ligaments, capsular and muscular) interaction;
- insertion of the implant or resurfacing material;
- fixation of the implant or resurfacing material to bone;
- evaluation of composite bone/implant/soft tissue system (range of motion, balancing and stability, etc.);
- closure and repair of the surgically altered soft tissues; and
- post-operative follow-up and evaluation.

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.

In order to perform L/MIS, 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 modified, sometimes radically. Technically, we will need to develop accurate pre-operative planners and surgical simulators, less invasive surgical tools and more powerful intraoperative visualisation devices that can provide updated images of the bone surfaces and soft tissues being manipulated in a less invasive way. Eventually, miniature sensors and actuators will need to be incorporated into a trial or even the actual replaced artificial or natural joint surface in order to give feedback to surgeons both during and after the surgery.

Finally, in order to address the wide spectrum of clinical challenges faced by surgeons, various enabling technologies will need to be integrated into a complete L/MIS system. The development of the next generation of computer-assisted surgical planners and tools, coupled with bone tissue engineering techniques, will also permit the design and growth of biologic implant components that are customised and optimised for an individual patient.

We now recognise that CAOS technologies are part of the L/MIS 'surgical toolbox of the future' and represent a spectrum of devices including 3-D image-guided and non-image-based navigation systems, miniature robotic assistive tools and new intraoperative visualisation devices that provide 'X-ray vision' without the X-rays. There is no doubt that CAOS tools will enable more accurate

and less invasive surgical techniques. CAOS tools will also be used as the surgical trainers of the future by coupling simulations with realtime evaluations of surgical performance. Lastly, we will 'close the loop' in surgical practice by measuring and relating surgical techniques to patient outcomes directly. Therefore, these CAOS technologies represent a new generation of tools for clinicians, clinician-scientists and researchers that enable surgeons to achieve the surgical goal through smaller and smaller incisions whilst improving accuracy and precision, reducing complications and speeding patients' recoveries.

Training and Development of Surgical Techniques

By coupling what machines do well (including computers, robotics and navigational tools) with what humans do well, in order to complete a task better than either could do alone, we will enable surgeons to develop techniques that are not only more accurate, but also minimally invasive. The merging of MIS and CAOS will naturally lead to the development of new surgical techniques that were never possible before.

There is little doubt that MIS coupled with CAOS

technologies has the potential to impact daily clinical practice in adult reconstructive surgery. However, there will likely be a steep 'learning curve' in the adoption of these newer L/MIS techniques. Therefore, the education of the practising orthopaedic surgeon on the use of the next generation of surgical techniques and tools is very important. In order to meet this educational challenge, a symposium series began in 2003, entitled "Less and Minimally Invasive Surgery for Joint Arthroplasty: Fact and Fiction", nicknamed "MIS meets CAOS". The symposium provides the forum to discuss the current status and future roles of less and minimally invasive joint reconstructive surgery. The programme brings together world leaders and combines didactic sessions with hands-on surgical academy, designed to provide a comprehensive understanding of L/MIS, CAOS and clinical systems in the areas of new surgical techniques, mechanical tool and implant redesign and computer-assisted tools.

There is no doubt that there is a revolution happening in the way adult reconstruction surgery is being performed now and the way it will be performed in the future. This clinical revolution provides unique opportunities for clinicians, researchers and commercial development. ■