The Impact of Smart Tools on Total Knee Arthroplasty

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Abstract

Smart tools and robotic surgery are helping us take a step into the operating room of the future. As this technology develops, it can potentially help surgeons perform total knee arthroplasty (TKA) faster and with increased accuracy. In addition, this technology will reduce the number of instruments needed for the procedure, thus improving efficiency. As technology advances, smart tools may become commonplace in the operating room and may fulfill their potential to transform the way TKA is performed. Such potential is important, as there has been an exponential rise in the number of TKAs performed annually. The resulting demand on surgeons and hospital systems will necessitate improving technology so that it can be used to treat more patients while maintaining quality of care. Smart tools and robotic surgery may represent one answer to this demand.

With improvements in implant design and surgical instrumentation, total knee arthroplasty (TKA) has undergone an evolution over the past 30 years. Specifically, there have been improvements in the accuracy, reproducibility, and reliability of surgical instrumentation. The simple cutting guides of the past have been transformed into more accurate resection guides and tensors, which ensure more accurate bone resection and soft-tissue balancing. In recent years, minimally invasive surgery (MIS) has become popular with surgeons, patients, and even health care providers because of the anticipated benefits of smaller incisions, shorter hospital stays, and quicker recovery. MIS-TKA introduced instrumentation reduced in size to fit within the smaller operative field. Further developments coupled computer navigation with MIS in an attempt to improve the surgeon's visibility in a reduced operative field.

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As the operative environment becomes smaller, the impact and influence of technology become proportionally larger. Computer-navigated instrumentation has been developed to improve the position of the resection guides and ultimately the position of the final components. This new technology can be considered an enhancement tool or enabler in MIS-TKA because, after registration of the anatomical landmarks, the instruments are dynamically tracked with real-time feedback on the angle and depth of the femoral and tibial resection.

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Currently, there are 2 types of computer-navigated systems for TKA. Image-guided systems rely on data from preoperative plain films or computed tomography (CT) scans that need to be registered in the computer system. Imageless navigation systems eliminate the need for preoperative imaging and rely on registration of intraoperative landmarks. Instrumentation during the procedure can be tracked either by optical line of sight (with a series of arrays detected by an infrared camera) or with an electromagnetic (EM) system that uses trackers attached to the bone and an EM field generator. Each computer navigation system has its proponents.

Advocates of both types of computer-navigated surgery have reported in clinical studies that navigation has shown an improvement in the accuracy of component positioning within 3° of the desired position over conventional instrumentation.[1,2] Registration of anatomical landmarks and interpretation of these data by computer will ultimately set up the 3-dimensional (3-D) virtual model of the knee. Improved accuracy in the process of collecting the landmark data will create a more accurate virtual model and guidance system. The ideal system should be simple to use, accurate, and reliable and should not interfere with the operative field. It should be an enabler in the limited operative field and reliably report knee alignment and intraoperative kinematics.[3]

Technology is increasingly being used in the operating room, but computer navigation is not artificial intelligence, and it does not make any decisions. Current technology is surgeon-directed and should be a tool of confirmation, with the potential for improvements in surgical accuracy, reliability, and confidence. Although computer navigation may be the first step in improving TKA, newer technologies are moving surgical techniques even further along. Accuracy and safety of conventional instrumentation in TKA depend on the surgeon's judgment, experience, ability to integrate images, use of preoperative plain films, knowledge of anatomical landmarks, knowledge of knee kinematics, and hand–eye coordination. Recent advances in medical imaging, computer vision, and robotics have led to the development of enabling technologies, which are designed to develop interactive, patient-specific preoperative plans optimizing accurate surgery through use of smart tools.[4] The resulting synergistic use of computers and robotic technology assists orthopedic surgeons in performing procedures. Surgeons need to understand the goals, applications, and limitations of such systems.[5] Early robotic systems removed surgeon control from procedures, which created a perception of increased risk and a negative attitude toward use of robotics. However, recent developments have changed this attitude.

Many robotic systems are being developed. Robotic surgery is ideally suited to TKA. The ability to isolate and rigidly fix the femur and tibia in known positions allows robotic devices to be securely fixed to the bone or within the desired plan of resection.[6] The bone is treated as a fixed object, simplifying computer control of the robotic system. Developing ideal robotic systems requires that the technology be safe, accurate, compatible in size and shape with the operative field, and capable of being sterilized, and it must show measurable benefits, such as reduced operative time, reduced surgical trauma, and improved clinical outcomes.[7] Advocates of this technology believe these goals are attainable and that robot-assisted TKA can achieve levels of accuracy, precision, and safety not possible with computer-assisted surgery.[6]

After identifying fixed anatomical landmarks similar to contemporary navigation systems, robotic systems create a 3-D virtual model of the knee joint. In all such systems, a leg-holding device is used to rigidly secure the knee in the same position to ensure accuracy throughout the referencing stage and the procedure. This process establishes a relationship between the robot, the patient, and the surgical field. Using this information and the created virtual model, the robot helps the surgeon to perform the guided surgery within a defined operative field. Commercially available robotic systems can be categorized as either passive or active devices. This classification depends on the surgeon's degree of control over the robot.

With a passive system, the surgeon and robot interact and communicate during the procedure. The robot can be a haptic robot or a nonhaptic robot. With a haptic robot, a preoperative plan, established by the input of fixed bone landmarks, determines the boundaries of the surgical area. The tactile feedback with the cutting tool allows the surgeon to feel the boundaries of the bone resection and prevents movement outside the planned operative field. For example, Acrobot (Acrobot Co, Ltd; United Kingdom) constrains the range of movement of the surgical tool held by a robotic arm.

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A nonhaptic robot helps the surgeon accurately position the cutting guides based on a preoperative plan and the recorded anatomical landmarks. The surgeon then performs the bone resection through the positioned cutting guide. There is no tactile feel to the resection, and the surgeon performs the resection through the cutting guide as he would do with standard instrumentation. The Brigit device that is being developed by Zimmer (Warsaw, Ind) is a multifunctional passive assistant with an automated arm that positions and holds the resection guide according to the surgeon's surgical plan.

In contrast to a passive system, an active system carries out a complete preoperative plan without surgeon intervention. After anatomical landmarks are registered, the automated cutting tool resects the femur and the tibia. Two active systems are Caspar (Universal Robot Systems; Germany) and Robodoc (Integrated Surgical Supplies, Ltd; Sacramento, Calif). Both of these systems direct a milling device automatically, according to preoperative planning.[8] They use preoperative CT images as part of the preoperative templating, including the angle and depth of the bone resection and the size of the components. After intraoperative registration of the anatomical landmarks, the computer matches the data with the CT image, and a virtual model of the knee is created. The surgeon then guides the robotic cutting tool to the desired location, and the robot prepares the bone autonomously. When bone preparation is complete, the surgeon completes the TKA by balancing the soft tissues and implanting the components.

Although some surgeons are apprehensive about active robots and automated surgery, passive systems, as discussed above, are being developed that may change the perception of increased risk and the negative attitude toward robotics and may improve surgeon accuracy. With a passive automated system, the surgeon maintains control throughout the procedure (and control is something one does not want to relinquish). He or she selects the anatomical landmarks, which establishes the coordinate system that creates the virtual 3-D knee model that guides the instrumentation. Surgeon input is preserved with confirmation of implant size, resection angle, component rotation, and resection depth, all of which can be adjusted before final positioning of the automated cutting guide. Once the cutting guide is guided into place, the surgeon resects the femur and tibia, as is routinely done with standard instruments. Further concepts in development include smart tools that, besides guiding bone resection, will provide intraoperative quantifiable information on soft-tissue balancing, alignment, range of motion, and kinematics.

Smart tools and robotic surgery are helping us take a step into the operating room of the future. As this technology develops, it can potentially help surgeons perform the procedure faster and with improved accuracy. In addition, this technology will reduce the number of instruments needed for the procedure, thus improving efficiency. As technology advances, smart tools may become commonplace in the operating room and may fulfill their potential to transform the way TKA is performed. Such potential is important, as there has been an exponential rise in the number of TKAs performed annually.

With the aging of the baby boomers, the increase in the number of people with arthritis, and the reported success of TKA in improving quality of life, the number of TKAs performed annually is rising. Kurtz and colleagues[9] recently predicted that the number of primary TKAs performed annually will increase to 3.48 million by 2030. This resulting demand on surgeons and hospital systems will necessitate improving technology so that it can be used to treat more patients while maintaining quality of care. Smart tools and robotic surgery may represent one answer to this demand, as they can lead to a reduction in the amount of instrumentation needed. For hospitals, fewer instruments mean a decreased need for sterilization and storage and hence lower handling costs for the procedure. Surgeons may eventually realize that smart instruments can simplify the procedure (fewer instruments and surgical steps) and, with improvements in technique and technology, may also reduce operating time. This is new, innovative technology. It remains to be seen whether history will look on the development of robotic surgery as a profound exemplary shift or as a bump on the road to something more important.

Author's Disclosure Statement

Dr. Scuderi wishes to note he is on the speaker's bureau for Zimmer, Inc., serves as a consultant to Zimmer, Inc, and is a significant shareholder of Zimmer, Inc.

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