The Utility of Robotics in Total Knee Arthroplasty

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In the last decade, instrumentation for total knee arthroplasty (TKA) has improved the accuracy, reproducibility, and reliability of the procedure. In recent years, minimally invasive surgery (MIS)-TKA introduced instrumentation that was reduced in size to fit within the smaller operative field. As the operative field becomes reduced in size, the impact and influence of technology becomes proportionately larger [1]. The introduction of computer navigation with MIS is an attempt to improve the surgeon's visibility in a reduced operative field. The intended goal is to improve the position of the resection guides and ultimately the position of the final components, in essence, providing improved visualization in the limited field. This new technology is an enhancement tool or enabler in MIS-TKA because, after registration of the anatomic landmarks, the instruments are dynamically tracked with real-time feedback on the angle and depth of the femoral and tibial resection. Currently, there are two types of computer-navigated systems for TKA: imaged-guided and imageless systems. Image-guided systems rely on data from preoperative radiographs or computed tomography (CT) scans that are registered into the computer system. Imageless navigation systems eliminate the need for preoperative imaging and rely on the registration of intraoperative landmarks and then compare the registered data with a library of anatomic specimens recorded within the computer databank. The next distinctive feature is the mode of instrument tracking, which can be either by optical line of sight with a series of arrays that are detected by an infrared camera, or an electromagnetic (EM) system that utilizes trackers that are attached to the bone and an EM field generator. Each computer navigation system has their proponents. Either way, advocates of computer-navigated surgery have reported in clinical studies that navigation has shown an improvement in the accuracy of component position within 3° of the desired position over conventional instrumentation [2, 3]. The computer relies on the registration of anatomic landmarks and interprets this data to create a three-dimensional (3D) virtual model of the knee. Refinements 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 without interfering with the operative field and should serve as an enabler in the limited operative field, reliably reporting the knee alignment and intraoperative kinematics [4].

Although it may be appealing to rely on computer navigation to perform a TKA, it is not artificial intelligence and does not make any of the surgical decisions. The procedure still is surgeon

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directed, and navigation should serve as a tool of confirmation with the potential for improvements in surgical accuracy and reproducibility. Computer navigation is the first step in introducing advanced technologies into the operating room. The accuracy and safety of conventional instrumentation in TKA have always been dependent on the surgeon's judgment, experience, ability to integrate images, ability to utilize preoperative radiographs, knowledge of anatomic landmarks, knowledge of knee kinematics, and hand-eye coordination. Recent advances in medical imaging, computer vision, and robotics have provided enabling technologies. Synergistic use of computers and robotic technology, which are designed to develop interactive patient-specific procedures, optimizes the accurate performance of the surgery [5]. The successful use of this technology requires that it not replace the surgeon but support the surgeon with enhanced feedback, integration of information, and visual dexterity. The surgeon needs to clearly understand the goals, applications, and limitations of such a system [6].

TKA is ideally suited for the application of robotic surgery. 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 [7]. The bone is treated as a fixed object, simplifying the computer control of the robotic system. In developing the ideal robotic system, the technology must be safe; accurate; compatible with the operative field in size and shape, and be able to be sterilized; and must show measurable benefits, such as reduced operative time, reduced surgical trauma, and improved clinical outcomes [8]. Advocates think that this is attainable and that robotic-assisted TKA can achieve levels of accuracy, precision, and safety not accomplished by computer-assisted surgery [7].

The robotic systems rely on the creation of a 3D virtual model of the knee joint, which is formed from the identification of fixed anatomic landmarks. With all systems, the knee is rigidly secured in the same position with a leg-holding device throughout the referencing stage, as well as during the procedure to ensure accuracy. This establishes a relationship between the robot, the patient, and the surgical field. Using this information and the created virtual model of the knee, the robot enables 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 is dependent on the control the surgeon has on the robot. With a passive system, the surgeon and robot interact and communicate during the procedure. While there is surgeon apprehension about active robots and automated surgery, passive systems that are in development may relieve the negative impression of robotics, the perception of increased risk, and potentially improve the surgeon's accuracy. A passive robotic system maintains surgeon control, which one does not want to relinquish, throughout the procedure. The surgeon selects the anatomic landmarks, which establish the coordinate system that creates the virtual 3D model of the knee that guides the instrumentation. Surgeon input is preserved with confirmation of the implant size, the angle of resection, component rotation, and depth of resection. All of these factors can be adjusted prior to final positioning of the automated cutting guide. Once the cutting guide is guided into place, the surgeon resects the femur and tibia, as the surgeon would routinely do with standard instruments. Further concepts in development will provide intraoperative quantifiable information on soft tissue balancing, alignment, range of motion, and kinematics.

Passive robotic systems can be either with 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 of the planned operative field. Examples of this are the ACROBOT (Acrobot Co. LTD, United Kingdom) and the Haptic Guidance System (HGS) (MAKO Surgical Corp., Ft. Lauderdale, FL), which constrain the range of movement of the surgical tool held by a robotic arm. HGS is a haptic surgeon-assisted robotic system that allows the surgeon to accurately plan the implant size and optimize the position and orientation of the implant relative to a CT scan acquired preoperatively. The system eliminates the need for cutting guides that are used in conventional knee arthroplasty. During the bone resection, the HGS system with its proprietary software continuously provides the surgeon with visual, tactile, and auditory guidance [9].

The nonhaptic robot assists the surgeon in accurately positioning the cutting guides based upon a preoperative plan and the recorded anatomic 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 the surgeon would do with standard instrumentation. BRIGIT (Zimmer, Warsaw, IN) is a system in development that is an example of a passive robot. It is a multifunctional tool that serves as a passive assistant through an automated arm that positions and holds the resection guide according to the surgeon's surgical plan. The surgeon performs each step in the planned femoral and tibial resection for the desired knee implant as the robotic arm with the multifunctional cutting guide is positioned in place for each bone resection. The orientation and depth of resection is determined by the system software and confirmed by the surgeon. The bone resection is performed with a conventional saw. There is no tactile guidance during the bone preparation. The advantage of the robotic multifunctional cutting guide is that it eliminates the vast majority of instruments needed to perform the procedure, and the multifunctional cutting guide does not have to be pinned in place. It is locked in the plane of resection by the system during bone resection.

In contrast to a passive system, an active system follows a complete preoperative plan, which is carried out without surgeon intervention. After registration of the anatomic landmarks, the automated cutting tool resects the femur and the tibia. Examples of an active system are CASPAR (Universal Robot Systems, Germany) and ROBODOC (Integrated Surgical Supplies LTD, Sacramento, CA), which direct a milling device automatically according to preoperative planning [10]. These systems use preoperative CT images as part of the preoperative templating, including the angle and depth of bone resection and the size of the components. After intraoperative registration of the anatomic landmarks, the computer matches this data with the CT scan and a virtual model of the knee is created. The surgeon then guides the robotic cutting tool to the desired location and the robot then prepares the bone autonomously. Upon completion of the bone preparation, the surgeon completes the TKA by balancing the soft tissues and implanting the components.

Robotic surgery is helping us take the next step into the operating room of the future. The role of robots in the operating room has the potential to increase as technology improves and appropriate applications are defined [1]. Joint replacement arthroplasty may benefit the most due to the need for high precision in placing instruments, aligning the limb, and implanting components. In addition, this technology will reduce the number of instruments needed for the procedure, improving efficiency. As technology advances, robots may be commonplace in the operating room and potentially transform the way TKA is done in the future. This is important because there has been an exponential rise in the number of TKA performed annually. With baby boomers coming of age, the rise in the number of people with arthritis and reported success of TKA in improving the quality of life, the number of TKA performed annually is rising. A recent report by Kurtz predicted that the number of primary TKA performed annually will increase to 3.48 million by 2030 [11]. This demand on surgeon and the hospital system will need improvements in technology in order to treat more patients and maintain the quality of care. Robotic surgery is a new innovative technology and it will remain to be seen whether history will look on its development as a profound improvement in surgical technique or a bump on the road to something more important.

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