Integrating Robotic Technology Into the Operating Room

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ABSTRACT

Integration of any highly complex technology into the operating room is challenging but can be accomplished with dedicated engineers, trained surgical team members, a streamlined surgical setup, and efficient surgical technique. Early results suggest a short learning curve and excellent radiographic outcomes (2.5 times improvement in tibial alignment, lower SD). The robotic arm is a valuable tool in modern orthopedics.

The typical orthopedic operating room (OR) has become very complex. It seems that, with each passing year, increasingly complex devices threaten to overwhelm OR staff and surgeons with their numbers and variety, at times making it difficult to focus on the main task—delivery of consistent, efficient, high-quality patient care. This situation must be viewed against the backdrop of growing patient volume (a result of the aging of the Baby Boom generation) and greater pressure on surgeons to increase surgical volume to offset losses caused by declining reimbursement.[1]

Many surgeons have turned to technology for solutions to the age-old problems of consistency and quality, but it is generally accepted that incorporating any new device adds both complexity and time to surgical procedures. Recently, we began using a surgical robotic arm, the MAKO Tactile Guidance System (TGS; MAKO Surgical Corp., Fort Lauderdale, FL), to improve accuracy of implant positioning and ligament balancing in unicompartmental knee arthroplasty (UKA). Our preliminary data show that accuracy of implant positioning is better by a factor of 2.5 in the sagittal plane and by 3.2° in the anteroposterior plane in comparisons with the accuracy of our previous instrumented UKAs.[2] Given these positive results, the questions then are how we can integrate highly complex robotic systems into high-efficiency ORs, and, as a corollary, whether these improvements in accuracy and ligament balance are worth the extra time, effort, and expense involved in integrating new technology into the OR.

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ROBOT ENGINEERING

The first step toward robot efficiency is at the design level, with software designers and engineers aiming for a streamlined, user-friendly interface. TGS software developers have worked to ensure an efficient workflow that limits time-consuming UKA aspects, such as bone registration and burr changes, and speeds other aspects, such as bone burring.

The second step involves integrating the robotic machine into the OR and its sterile environment. The machine is ungainly, and the robotic arm large and protruding, which can make machine placement, draping, and attachment of sterile tools difficult. Designers continue to work to simplify these important aspects of operating efficiency, and substantial gains have been made in the past year. Improvements have been made in draping and attachment methods for the robotic tools used in the procedure.

SURGICAL TEAM EFFICIENCY

Perhaps the most important aspect of integrating robotics into the OR is team efficiency. The aforementioned issues of placing and draping a large machine, sterile draping of the robotic arm and implements, and patient positioning, draping, and robotic arm registration can all be performed by a well-trained surgical team before the surgeon enters the operating theater (Figure 1). If the timing is correct, and a 2-room operating model is used, little time is lost, as the surgeon can complete a case while the next case is being set up and can then enter the robot suite at the proper moment to verify the surgical plan and initiate the operation. Likewise, the team can assemble optical trackers and probes and facilitate burr changes while the surgeon focuses on the actual surgery.

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Figure 1. Surgical team drapes patient and robotic arm before surgeon enters operating room.

Figure 2. Simple back-table setup for robotic surgery: no cutting blocks, minimal instrumentation, few retractors.

Streamlined Surgical Setup

One of the greatest efficiencies of robotic surgery is in instrument setup. As the cutting tool is computer-guided, there is no need for cutting blocks, alignment rods, and bulky instrument trays. Eliminating these items frees up much of the back table and allows the scrub team to concentrate on setting up the robot rather than the instruments (Figure 2). Only trial components are needed, and, as the entire procedure is planned on the computer, and implant sizes are known, only the trials for the actual implant sizes necessary must remain in the room. This situation leads to efficiencies in room cleanup and restocking, which facilitate subsequent procedures as well.

Efficient Surgical Technique

Once the team is trained and instrumentation streamlined, it is up to the surgeon to be as efficient as possible. As familiarity with software and robot techniques increases, efficiency naturally improves. The surgical approach should be kept reasonably small to obtain the rehabilitation benefits of minimally invasive surgery. Although robotically enabled bone cuts can be made through a very small incision, it is best early on to avoid struggling with soft tissues and to make an incision large enough for easy insertion of the relatively large femoral component while the knee is in flexion.

Observing the on-screen anatomy, the 3-dimensional computed tomography reconstruction of the bone, allows for accurate placement of registration landmarks and thus speedier registration. Final implant position can be adjusted after bone registration and dynamic ligament stressing, thus allowing anatomical positioning of the components with normal tensioning of the collateral and cruciate ligaments.

The “footprints” for the femoral and tibial implants are quickly cut with the high-speed burr and tactile guidance, eliminating the risk for errors in cutting. All 6-mm burr cuts are made first, then there is a single burr change, and then the 2-mm router bit is used to finish the keels of the femur and the tibia. Minimizing the number of burr changes reduces downtime in the OR (Figures 3, 4).

Results

The usability of a surgical tool is perhaps best measured by its ease of integration into an existing system. We began using the TGS in June 2007, and soon thereafter the robotic system became part of our operating routine. Initial surgeries took 80 to 120 minutes, but, by adopting the efficiency measures described earlier, we were soon able to reduce tourniquet time to under 40 minutes, which compares favorably with our usual UKA time. More important, even though the technology and the system were new, our radiographic and clinical results were excellent (no poor results or outliers cause by learning curve errors). Comparing our first 36 robotic arm patients with our last 45

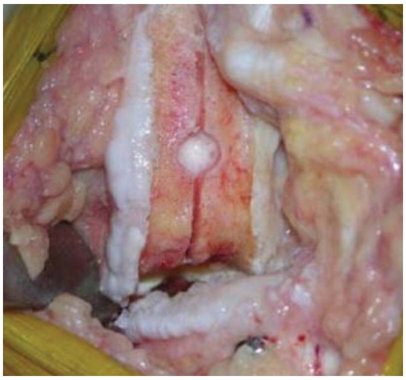


Figure 3. Distal femur after robot preparation.

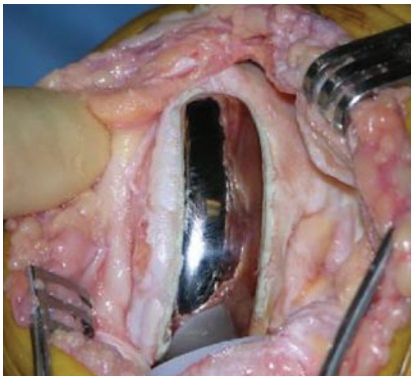


Figure 4. Final components after robot preparation.

Figure 5. Typical radiographic appearance of robotically placed inlay unicompartmental knee arthroplasty, anteroposterior view.

manually instrumented patients, in age- and sex-matched groups, we found the accuracy of the tibial implant slope to be 2.5 times better (*P*<.05), varus alignment to be 3.2° better (*P*<.05), and SD to be 2.8 times less (*P*<.05) in the robotic arm group (Figures 5–8). This ability to reproduce a surgery is perhaps the greatest benefit of using a robotic system.

CONCLUSIONS

Integration of any new technology into a complex environment involves challenges on several levels. With the assistance of dedicated engineers, practiced surgical team members, a streamlined instrument setup, and efficient surgical technique, robotics can be successfully applied to the orthopedic operating environment. Although results are preliminary, dramatically improved surgical accuracy and improved ligament dynamics lead me to conclude that the future of robot-assisted surgery is bright, and the temporal and economic sacrifices required are eminently worthwhile.

Figure 6. Typical radiographic appearance of robotically placed inlay unicompartmental knee arthroplasty, lateral view.

AUTHOR'S DISCLOSURE STATEMENT

Dr. Coon wishes to note that he is a paid consultant to, and designing surgeon for, MAKO Surgical Corp. The author acknowledges the grant from MAKO Surgical Corp. in support of publishing this supplement.

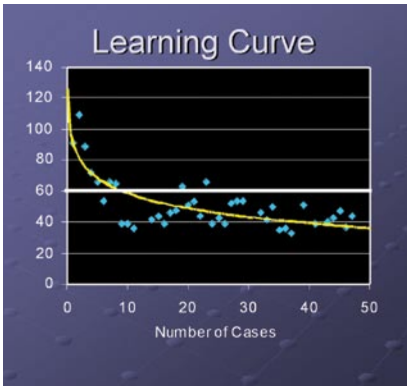
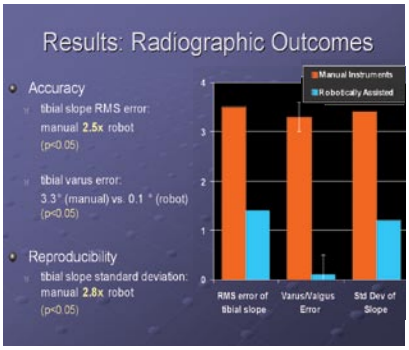


Figure 7. Early learning curve, first 50 cases, robotic unicompartmental knee arthroplasty.



Results: Radiographic Outcomes

- Accuracy
  - tibial slope RMS error: manual 2.5x robot (p<0.05)
  - tibial varus error: 3.3° (manual) vs. 0.1 ° (robot) (p<0.05)
- Reproducibility
  - tibial slope standard deviation: manual 2.8x robot (p<0.05)

Figure 8. Early radiographic results, first 36 robotic cases versus last 45 manually instrumented cases.

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