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Surgical technique

Robotic arm assisted total knee arthroplasty workflow optimization, operative times and learning curve

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ABSTRACT

Robotic arm assisted total knee arthroplasty (RTKA) has many potential benefits including advanced preoperative templating, restoration of mechanical alignment, accuracy of bony resection, robust safety mechanisms, and dynamic gap balancing. One of the most frequently quoted drawbacks preventing experienced surgeons from adopting this technology is the perceived increase in surgical time. This technique paper outlines the general concepts used to improve operating room efficiency as well as the step-by-step workflow to consistently perform RTKA with surgical times under 60 minutes. Although the clinical and functional results of RTKA are just beginning to be described in literature, this manuscript demonstrates that with proper technique and workflow, surgical time should not be a significant factor to deter surgeons from adopting this new technology.

Introduction

Robotic arm assisted total knee arthroplasty (RTKA) has gained popularity recently with the release of the Stryker Mako (Stryker Orthopedics, Kalamazoo, MI) robotic arm for total knee replacement in 2017. Prior to this, similar technology in the earlier generation Stryker Mako robotic arm had significant clinical success and popularity for its use in partial knee replacement [1-3]. Several of the major manufacturers have since released other variations of robotic arm assisted surgery or are in the process of developing them [4]. Several studies have validated many of the goals that robotic arm assisted surgery set out to accomplish. Although the literature is in its infancy, key advantages of RTKA which have been supported by the literature include improved component positioning and restoration of limb mechanical axis, improved preoperative templating with computed tomography (CT) technology, and early improvements in short-term clinical outcomes compared to conventional instrumentation [5-13]. Several studies have also shown equal or improved safety compared to conventional instruments. For example, robotic arm assisted surgery with safety zones has been shown to prevent iatrogenic damage to key surrounding soft tissues during TKA [14,15].

A significant barrier to widespread adoption of this technology is the perceived compromise of increased operative time and reduced operating room (OR) efficiency [12,16].

Surgical technique

Here we outline critical concepts for improving OR efficiency which can be applied to any robotic arm system and present a step-by-step description for reproducibly reducing operative times. We also report our learning curve in our first 132 consecutive unilateral RTKA cases. We hypothesized that with an efficient workflow and appropriate technique, surgical times for RTKA can average under 60 minutes.

General concepts

A team approach to performing TKA is key to OR efficiency. We attribute our success to reproducible steps, well-defined

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responsibilities in the OR, and a consistent surgical team. Although this is not always possible in every institution, surgeons should strive for consistency and reproducibility in their steps and members of their surgical team. Key components to efficiency in our opinion include maximizing the number of set up steps completed before the surgeon enters the room, performing steps simultaneously instead of consecutively by members of the surgical team whenever possible, and maximizing the benefits of CT-based preoperative planning and templating. We also recommend maintaining a workflow similar to standard instrumentation cases when adopting a new technique. This is key for the surgical team to minimize the number of steps they have to relearn and limiting stress in the OR. In addition to cadaveric training, the value of surgeon and surgical team visitation with someone experienced in RTKA cannot be overstated when first adopting RTKA.

Surgical workflow

For surgeons running 2 rooms, a single OR with a consistent surgical team should be the “robotic” room. This allows cumulative experience to be gained by the surgical team which in our opinion significantly shortens the learning curve. Surgeons running a single OR may apply the same concepts. A designated robotic OR ensures that equipment is stored in a manner that maximizes efficient movement of both patient and equipment. Storing all equipment in one central location also facilitates quick and easy access to all required instruments, disposables, and supplies. This room should ideally be large enough to allow unhindered movement of the robot and monitoring stations which will help prevent contamination.

Prior to the patient entering the room, the product specialist should load the preoperative plan on the monitors and verify all equipment is operational. The product specialist is the technician the manufacturer of the robotic arm system sends to prepare for and execute each case. The patient is then brought into the room and transferred to the OR table and anesthesia is administered. In our workflow, we use a standard right-angle foot positioner attached to the rail of the bed which allows the knee to be placed at 90° of flexion. We also use a lateral positioning board, which helps maintain the knee in a vertical position by preventing abduction of the hip (Fig. 1). This maximizes visibility of the reflective arrays from the sensing array and eliminates the need for an assistant to hold the knee in a vertical position while also attempting to stay out of the way of the arrays.

The leg is prepped and draped in standard fashion and circumferential iodine dressings are applied. Prior to the surgeon entering the room, the scrub technician drapes the robot and registers the saw blade with the assistance of the product specialist. An additional benefit of the streamlined protocol and the preoperative templating technology of RTKA is the reduced instrument requirements which include 2 general trays and 2 manufacturer provided trays (Fig. 2).

A video of an exemplary surgery is available in Appendix A. Upon the surgeon entering the room, time out is performed. The surgical procedure is initiated when the surgeon peels away a 2 × 2 cm of the iodine dressing with the leg in extension approximately 4 finger breadths distal to the tibial tubercle and inserts 2 threaded Steinmann pins which secure the tibial reflective array. As the surgeon inserts the pins to secure the femoral reflective array 4 finger breaths above the patella at a 45° angle to the vertical, the scrub technician mounts the tibial reflective array and verifies appropriate position with the assistance of the product specialist. As the surgeon registers the medial and lateral malleolus, the scrub technician assembles the femoral reflective array. The extremity is then taken through short arcs of motion to register the hip center. The importance of overlapping steps by team members is demonstrated here. Exsanguination is only performed once all calibration and motion sensory registration is complete, which reduces the overall tourniquet time. In approximately 4 minutes the surgeon is ready to begin their standard approach to the knee.

We use a quad-sparing midvastus approach for RTKA. We have found that the amount of exposure, dissection, and length of required incision with RTKA is less than in our manual total knee

Figure 1. Lateral leg positioning board helps to maintain vertical position of the leg by preventing hip abduction. This provides maximum visibility of reflective arrays. A right-angle foot positioner is also used, allowing placement of the knee at 90°.

Figure 2. Back table demonstrating 2 general instrument trays (left) and 2 manufacturer supplied trays including trials and saw blade (right). Total of 4 trays required for this case.

arthroplasty (MTKA) cases due to less need to directly visualize bone cuts. The synovium in the suprapatellar pouch and cruciates are removed with electrocautery and the fat pad, menisci, and medial release of deep medial collateral ligament are performed sharply. We stress the importance of staying as consistent with your traditional exposure as possible to maximize efficiency. After medial release is performed and the tibia is exposed, a check point is placed by the assistant as soon as the surgeon exposes the structures. Care is taken to make sure that the trackers are placed out of the zone of resection. This is done in similar fashion for the femoral check point at the medial condyle.

At this point, registration begins with the knee at 90° of flexion. Holding the shaft of the wand with one hand and stabilizing the stylus tip with the other, bony landmarks on the femur are registered to the preoperative CT with the registration software. It is important to note that with the Mako system used in this study, registration is done in groups of 4 points. With each fourth point registered, the tone generated by the software with each press of the pedal changes. Therefore, we recommend the surgeon look up at the screen only to determine which 4 points they are registering. Then, with each step of the pedal, which is placed under the right heel of the surgeon, the surgeon looks at the surgical field not the monitor and listens for the

Figure 3. Modeled gap balancing performed prior to any bony resection allows adjustments to the preoperative plan conducted via discussion with product specialist.

tone of the beeps to change. Once the tone changes and the 4 points are registered, the surgeon looks up to see what the next 4 points to be registered are and repeats the sequence. We noticed this technique significantly improved our accuracy and efficiency. Surgeons using a different system should similarly identify a workflow for registering efficiently.

The preoperative plan with resection levels and expected flexion-extension gaps is then evaluated while taking the knee through a range of motion (Fig. 3). At this point, it is determined if the medial and lateral gaps in flexion and extension are balanceable and the resection level is adequate to fit the smallest insert and implants (Fig. 4). In our workflow, we allow up to 3° of variation from the mechanical axis with our varus/valgus angle to maximize medial/lateral gap balancing. The knee is then positioned at 90° of flexion, the table lowered, and collateral ligament retractors placed and held using lap sponges. This allows the first assist to retract at a distance so as to not block the arrays or robotic arm while preparing for bony cuts. Saw blade and checkpoint registration are confirmed by the surgeon using the green handled stylus.

Bony resections of the tibia are completed first, with the tibial cut left in place to protect the cut surface of the tibia while performing the femoral cuts (Fig. 5). We found the most efficient order to cut the femur is posterior, anterior, then anterior chamfer followed by blade switch, and finishing with the distal and posterior chamfer cuts. We place the handle of the robotic arm in the vertical position for the tibia and anterior/ posterior cuts and in the horizontal position for the anterior chamfer cut as we find this is most efficient and comfortable for the surgeon. As the anterior chamfer cut is being made the first assist has the saw blade for the distal cut in hand and is prepared to make a blade change as soon as the surgeon completes the cut. As the first assist changes the blade the surgeon removes the anterior, posterior, and chamfer cuts with an osteotome and rongeur. Again, emphasizing the importance of overlapping steps by team members.

The surgeon then registers the femoral checkpoint and saw blade and makes the distal femoral cut and posterior chamfer with the handle in the horizontal position. After all cuts are made, the remaining soft tissue elements, osteophytes, and tibial cut are removed, and the posterior medial capsule is injected. We recommend 2 hands on the robotic arm by the surgeon at all times as there is 0.5-mm play in resection depth allowed by the robot. We feel this improves efficiency and accuracy and eliminates having to pass through the same area more than once with cuts. We also recommend that all cuts are made with the surgeon looking at the screen and that the entire width of the blade is used with each pass. This minimizes unnecessary passes to complete these cuts. The most potentially dangerous part of the procedure is when cutting the tibia where the blade may contact the patellar tendon. We recommend careful attention during this step and directing the robotic arm from a medial to lateral direction when cutting the lateral tibial plateau as to avoid damaging the tendon with the excursion of the blade.

Trial components are placed and real time gap balancing is performed by taking the knee through a range of motion. At this point, fine tuning of gap balancing can be performed if needed with soft tissue techniques or with bone resection techniques in 0.5-mm increments depending on the surgeon's balancing philosophy. In this case, the knee was symmetrically tight laterally in extension and flexion, so a 1-mm valgus tibial recut was performed to balance the knee. This is our preferred technique as we find that performing a 1-mm bone resection is more accurate and predictable than performing soft tissue releases. We perform selective resurfacing of the patella in patients with grade 3 or 4 arthritic changes to the patellofemoral joint, which is performed using a free hand technique. We do this prior to removal of the trial components. Irrigation and implantation of final components is then performed. We close with a running barbed suture for the capsule, running vicryl for the dermal layer, and monocryl subcuticular closure with dermal glue. The tourniquet is deflated once the final dressings have been applied.

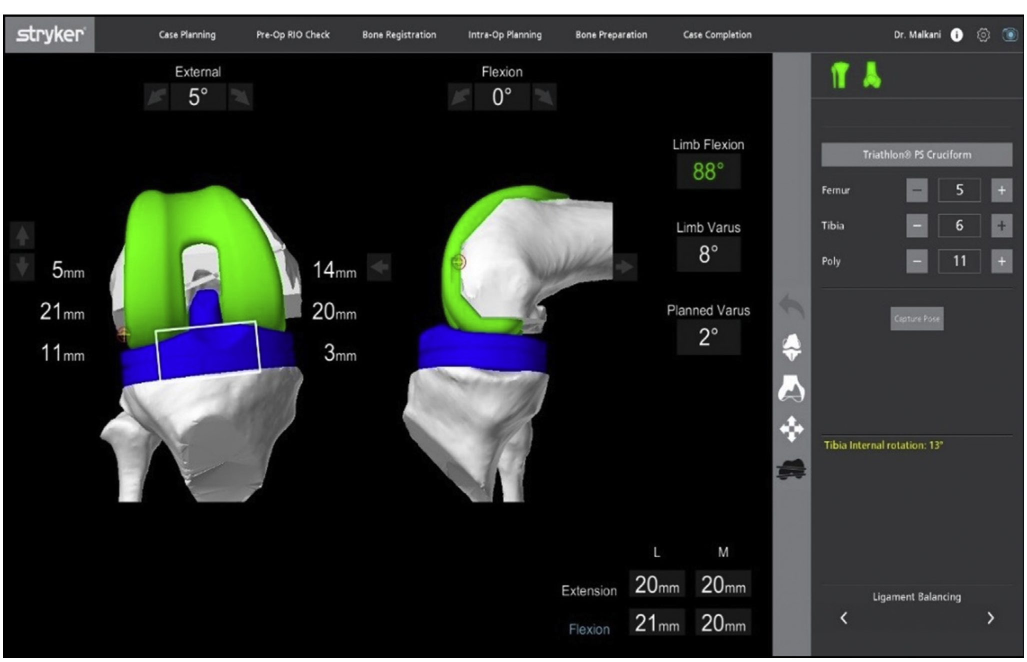

Figure 4. Live modeled gap balancing demonstrating flexion and extension gaps balanced to within 1 mm (bottom right) conducted by taking knee through range of motion and stress testing with varus and valgus stress.

Figure 5. Tibial resection performed with assistant retracting by utilizing curved retractors placed on the medial and lateral sides of the joint and then held with lap sponges allowing unobstructed view of reflective arrays from sensing array tower.

Operative time evaluation

The first 132 consecutive unilateral RTKA cases performed by the senior surgeon were retrospectively reviewed for tourniquet times. These times included wound closure and application of dressings. Cases were divided into 3 groups: group 1 cases 1-40, group 2 cases 41-80, and group 3 cases 81-132. Descriptive statistical analysis is shown in Table 1. *t*-Test analysis comparing groups was performed. A statistically significant difference was demonstrated between the average surgical time for groups 1 and 2 but not groups 2 and 3. This indicated that the inflection point of the learning curve occurs in under 40 cases. Of note, the average time, maximum time, and standard deviation all declined with added experience.

Cases were also stratified based on the use of cemented or cementless implants (Table 2). It was demonstrated that there was a statistically significant difference between these 2 groups as well. On average, the cementless RTKA took 4.1 minutes less than the cemented cohort. The cementless group also demonstrated increased consistency with regards to surgical time as evidenced by the narrower standard deviation. The difference between the longest cemented and longest press-fit RTKA was 13 minutes.

Discussion

The decision to begin utilizing RTKA technology is multifactorial. Although improved precision, accuracy, safety, and clinical outcomes have been supported in the literature, added surgical time and a learning curve have been quoted as drawbacks. This technique paper demonstrates that RTKA can be performed consistently and reproducibly with tourniquet times under 60 minutes.

The importance of dedicated staff as well as defined steps and responsibilities by all members of the surgical team cannot be overstated. Empowering the surgical team to perform tasks in tandem with the surgeon and overlapping steps greatly improves the overall efficiency. Surgeon familiarity with registration of landmarks, bony resection technique, tracker placement, retractor placement, and blade change are all areas that significant improvement with added case experience can be expected.

When adopting a new surgical technique, the learning curve is always a factor. RTKA has been demonstrated to have a relatively short learning curve in regard to operative time. Huq et al [7] prospectively collected operative times for 60 MTKAs followed by 60 RTKAs performed by a surgeon who had previously only had cadaveric experience with RTKA. In their study, a sharp decline in operative times was demonstrated after the seventh case. It was also noted that in regards to implant accuracy and complication rates there was no learning curve, indicating immediate improvements in accuracy without added risk to the patient. Plaskos et al [9] retrospectively reviewed the first 100 RTKAs at their institution and demonstrated that within 20 cases they were able to achieve operative times within 5 minutes of MTKA. Our learning curve was approximately 6 cases before surgical time reached 1 standard deviation of the average for the subsequent 132 cases. Our average surgical time from incision to placement of dressings was consistently under 1 hour.

It is too early for RTKA to have demonstrated superior long-term functional outcomes compared to MTKA [5,17]. However, several studies have already shown improved accuracy and precision of implant positioning, improved balancing, and equal or better safety in regard to iatrogenic soft tissue injury compared to MTKA [5,11,12]. Moreover, in a recent study by Haddad et al [13], the authors reported decreased postoperative pain, analgesic requirement, number of therapy sessions, and time to hospital discharge with RTKA compared to MTKA.

Although robotic technology is not necessary to perform a technically well-executed TKA, we do feel it is a powerful tool for the arthroplasty surgeon. In our experience, RTKA has changed the way we balance knees. It places numerical values to our balancing and allows us the precision to make fine adjustments. This technology affords us the ability to make 0.5 mm or 1° adjustments to fine tune our balancing and implant position. In terms of efficiency, the time dedicated to bony resection is generally less, which is likely attributed to improved planning which decreases the likelihood of having to repeat cuts multiple times [8]. Although in the majority of cases bony recuts are not needed, we demonstrate in this case how a 1-mm valgus recut of the tibia was used to balance the knee while adding only minimal time to the case.

Summary

RTKA is a new and innovative technology that has the potential to improve surgeon accuracy and patient outcomes but also presents concerns of added surgical time and a learning curve. The long-term clinical and functional outcomes of RTKA compared to MTKA are still in need of further study. This manuscript demonstrates that with proper technique and workflow, tourniquet times can consistently average below 60 minutes and should not be a significant factor deterring surgeons from adopting this new technology. It is without question that RTKA is a powerful tool. The question now is how we can best use this tool to improve patient outcomes and develop it further.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.artd.2019.04.007.

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