Tips and Tricks: Robotic-Assisted Total Knee Arthroplasty

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Introduction

Total knee arthroplasty (TKA) surgical rate has been increasing in a monotonic fashion since the introduction of modern prosthesis designs in the 1970s.[1] TKA is now one of the most frequently performed operations by orthopaedic surgeons in the United States, with surgical volume expected to reach 3.48 million cases per annum in 2030.[2] Despite the introduction of advanced prosthesis designs, reproducible surgical technique, thoughtful pre-surgical optimization, and contemporary post-surgical rehabilitation, studies have demonstrated that patient outcomes have plateaued, with approximately 20% of patients are dissatisfied with their surgical outcome.[3] With the substantial increase in surgical volume comes a concomitant increase in the number of dissatisfied patients. This looming increase in suboptimal outcomes has lead surgeons to innovate methods for optimizing outcomes following TKA.

Successful TKA requires several critical components: restoration of knee biomechanics, precise tibial and femoral bone cuts, accurate alignment of articulating components, balancing of the soft tissues and knee stabilizers, and avoidance of patellar maltracking. Modern robotic total knee arthroplasty (rTKA) was introduced in 2015 to optimize the above surgical factors. The most studied rTKA system on the market utilizes a pre-operative computed tomography (CT) scan to understand the patient's preoperative bony anatomy and allows the surgeon to execute a pre-defined operative plan to accurately place implants and balance soft tissues.[4,5]

Despite the promise of technology-aided "precision surgery" offered by rTKA, these systems have a large upfront capital investment.4 rTKA also requires learning a new surgical system and offers a surmountable albeit present learning curve for surgeons, with operative times decreasing as surgeons become more comfortable with the system.[6] This learning curve is steeper for surgeons without arthroplasty-specific fellowship training.[7] While an ongoing area of research, there are significant positives to using rTKA technology. In a propensity-score matched cohort of 255 patients, prior researchers have demonstrated that total knee replacement performed with robotic assistance leads to lower length of stay and an increased odds of discharge to home over manual total knee arthroplasty.[8] In the appropriately indicated patient, robotic total knee replacement is a powerful addition to the surgeon's toolbox.

In this review, we present a systematic and reproducible method for performing rTKA with a semiactive, closed robotic system (Mako, MAKO Surgical Corporation, Ft. Lauderdale, FL).

Indications

In patients who are indicated for TKA (e.g., end-stage arthritis recalcitrant to nonoperative measures without systemic factors that may pose an unacceptable anesthesia or infection risk), the surgeon must then consider if the patient is able to undergo rTKA. The surgeon must consider the following patient factors:

- Sufficient range of motion of the hip joint to allow for bony registration at time of surgery.
- Absence of metal in the proximity of the knee joint. Metal in close proximity to the planned surgery may result in photon starvation and beam hardening artifacts within the pre-operative CT scan,[9] which may limit the ability of rTKA software to map the patient's anatomy.
- Absence of infection within the host at time of surgery. Acute and chronic infection, both local and systemic, should be ruled out prior to surgery.
- Poor bone quality which may affect implant stability.
- Patient size. Large patients may limit the ability of the rTKA arm to assist in bone resection.
- Poor ligamentous integrity which may prevent the restoration of a stable knee joint.
- The type and significance of the patient's present deformity, which may limit the

ability for registration and restoration of normal biomechanics.

Surgical Technique

Positioning

The patient is placed in a supine position on a regular surgical table. A bump consisting of a single rolled blanket is placed under the patient's ipsilateral hip. A nonsterile tourniquet is placed and secured around the patient's thigh.

Ensure the MAKO system is in the appropriate location prior to scrubbing. The body of the system should be on the patient's operative side, with the long axis of the system perpendicular to the surgical table centered at the level of the patient's hip. The camera system should be on the patient's contralateral side with an unobstructed view of the patient.

The patient is then prepped and draped in standard fashion for a TKA by the surgical team, all of which should be wearing standard surgical personal protective equipment.

The patient's incision is then marked using a sterile marker while the knee is on a sterile bump in approximately 70 degrees of flexion, starting from three fingerbreadths proximal to the superior pole of the patella and extending distally to the patellar tendon insertion on the tibial tubercle (Figure 1). Once marked, the patient's limb is exsanguinated and tourniquet is inflated to 100 mmHg above the patient's systolic blood pressure.

Exposure

Exposure down to the knee joint is similar to that of a manual TKA. An anterior midline surgical incision is made down to the patella using a #10 surgical blade. A medial parapatellar arthrotomy is made down to bone, leaving a cuff of medial retinacular tissue attached to the patella for later closure. A distal femur synovectomy is performed and the infrapatellar fat pad is resected to define the anterolateral aspect of the tibia. The patella is then subluxed laterally to expose the medial femoral condyle and the ACL is resected.

Anatomic Registration

Prior to bone cuts, the femoral and tibial arrays must be placed. First, the distal femoral pin footprint is marked with bovie cautery one fingerbreadth proximal to the most superomedial aspect of trochlea (Figure 2). After placement of the 4.5mm diameter bone pin, the array stabilizer is placed on the pin and a second pin is placed proximally to the first slightly off angle. Similarly, the tibial pin is then placed three fingerbreadths distal to the tibial plateau at the medial aspect of the incision. A stabilizer is inserted over the pin and another pin is inserted proximally to the first 30 degrees off center laterally from the anatomic axis of the leg. It is critical to ensure the array stabilizer barrels are firmly on bone prior to securing them to their respective pins. Two navigational arrays are placed on the connector jigs such that they are facing the infrared camera. The pins are placed in such a way to give as much clearance for the robotic cutting arm as possible and to avoid interference with the final implants (Figure 3).

A right angle retractor is placed between the lateral tibial plateau and patella to retract the patella laterally and protect the lateral collateral ligament (LCL), whereas a Z retractor is placed medially to protect the medial collateral ligament (MCL).

Bone checkpoint pins are then placed. The femoral checkpoint is placed as medial as possible at the level of the distal-most femoral pin, approximately 1 fingerbreadth posterior to the distal-most femoral pin to ensure it is clear of the anterior chamfer cut. The tibial checkpoint is placed

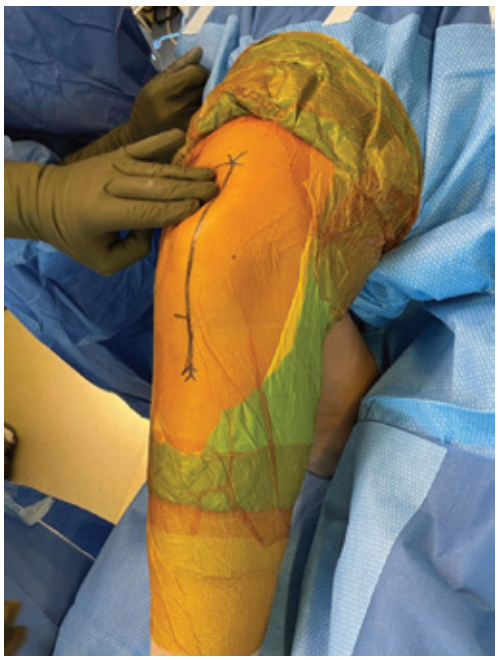

Figure 1. Incision placement allowing adequate exposure and respect of soft tissues.

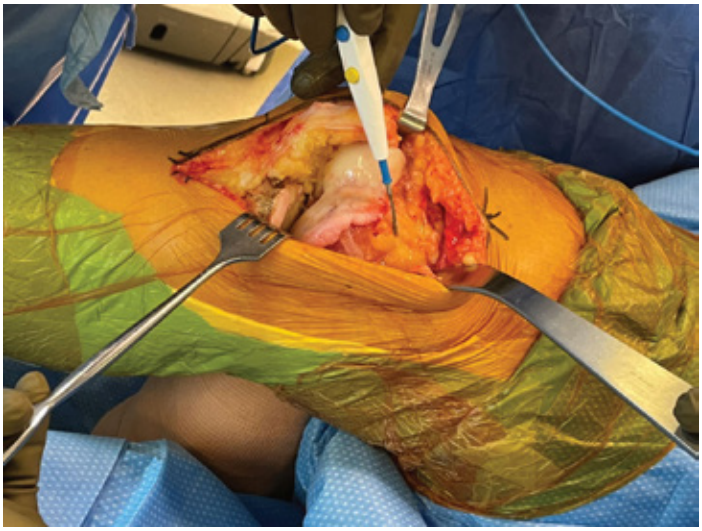

Figure 2. Bovie electrocautery marking of first (distal) pin for the femoral array.

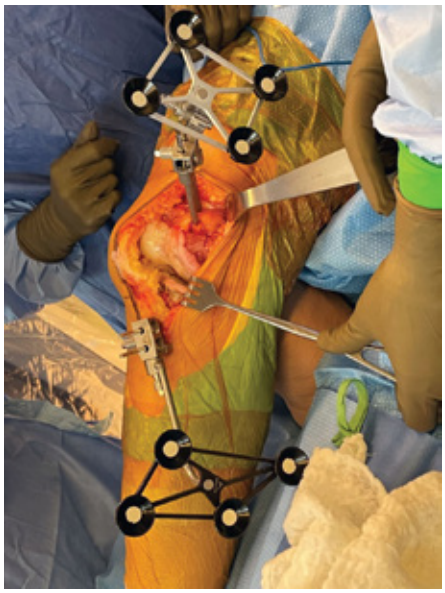

Figure 3. Final array placement. Note the array stabilizer barrels are on bone and are slightly off axis to allow unobstructed movement of the robotic arm and saw blade.

Figure 5. MAKO registration software screen during femoral registration demonstrating previous joint line (blue dots) and proposed joint line (grey shading) with planned implant position.

just proximal to the tibial array outside of the planned tibial cuts, approximately 1 fingerbreadth distal to the tibial plateau (Figure 4).

Next, the surgeon must undergo checkpoint registration using the MAKO software. Registration involves three steps: patient landmarks, bone checkpoints, and bone registration.

First, the hip center of rotation is calculated by circumducting the hip with the pelvis stabilized until verified by the MAKO software. The medial and lateral malleoli positions are then collected using blunt, green probe on each malleolus.

Second, the checkpoints are registered on the MAKO software using the blunt, green probe.

Third, bone registration is performed. Bone registration is completed by following the prompts on the MAKO screen (Figure 5) using the sharp probe to penetrate cartilage down to subchondral bone. The exact location of these points is not critical to successful registration, but the surgeon should ensure points are accurately registered on the surface of the subchondral and cortical bone, with care taken to have the probe sit precisely on top of the native cortical surface. Driving the probe deep into bone or superficially resting on cartilage will result in incorrect registration landmarks.

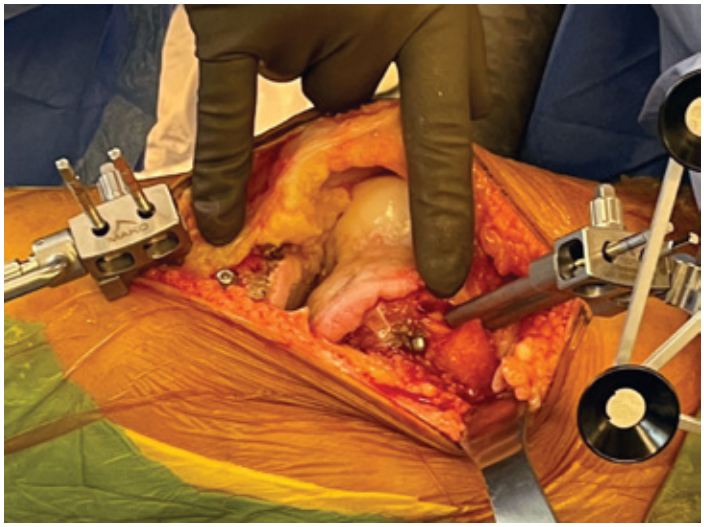

Figure 4. Location of femoral and tibial checkpoint pins.

Once registration is complete, the joint space can be evaluated throughout the range of motion, with particular attention paid to balance just short of full extension and at 90 degrees of flexion. Varus and valgus stress is applied to assess the predicted extension gap and a Chandler or Cobb elevator is used to assess the predicted flexion gap. Component position can be adjusted and soft tissue releases completed to ensure balanced flexion and extension gaps as predicted by the MAKO implant positioning software. Once component positioning is complete, proposed cuts should be reviewed to confirm appropriate bony resection and acceptable TKA parameters.

Bone Cuts

Bone cuts are performed using the MAKO robotic arm with the handle rotated laterally to allow quick transitions between the surgeons left and right hand for cutting and soft tissue retraction. The saw blade is controlled using an underhand grip with the ring finger or index finger actuating the saw as the surgeon transitions between hands as needed. At risk structures during cutting include the MCL, patellar tendon, and posterior structures. The haptic boundary drawn and enforced by the MAKO software/robotic arm provides some protection but diligent retractor placement is also critical, especially for the patellar tendon which is not protected by a haptic boundary.

Prior to performing any resections, the saw blade and femoral checkpoints are verified with the blunt probe to

confirm the infrared arrays have remained stable. Cuts are performed using the MAKO haptic boundaries and the previously determined surgical plan. The femur is cut first, starting with the distal femoral cut (starting with this cut is the authors preference as performing the distal femoral cut first allows for easier conversion to a traditional 4-in-1 cutting guide in the event that robotic equipment problems arise prior to completion of all femoral bony resections). Next the posterior femoral chamfer cut is performed followed by the posterior femoral cut, anterior femoral cut, and ending with the anterior chamfer cut (Figure 6).

Following the femoral cuts, the saw blade and tibial checkpoints are verified with the blunt probe. The tibial cut is performed again using the haptic boundaries defined by the MAKO software. Of note, patellar resurfacing, if indicated, is performed freehand without assistance of the robotic arm.

Gap balancing and Prosthesis Implantation

Following bone cuts, the surgery proceeds similar to a manual TKA procedure with some key differences. Once trial components are placed, varus and valgus stress is applied to the knee throughout the range of motion. The MAKO software and manual feedback are used to confirm stability and range of motion of the knee joint. Following this check, the trials, both arrays, and both checkpoints are removed. The tibia is prepared in typical fashion and final implants are placed. Of note, the increased precision of robotic bony resections facilitates the use of press-fit implants if this is the surgeons preference. Once implants are placed, the tourniquet is let down, hemostasis achieved with electrocautery, an analgesic cocktail is instilled into the soft tissues, and the surgical wound is closed in a layered fashion.

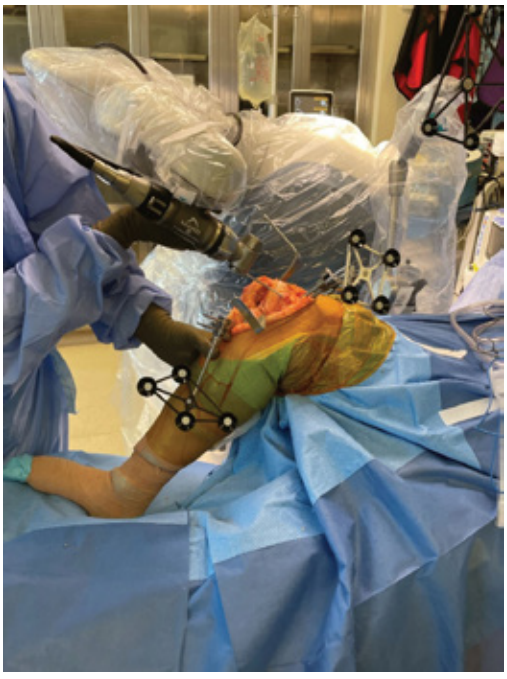

Figure 6. Anterior femoral cut.

Case Report

A 66-year-old female initially presented to our clinic with an 18 month history of anterior and posterior right knee pain. She had a history of prior left knee osteoarthritis status post manual total knee replacement over 10 years prior to her presentation. She failed conservative treatment including physical therapy, anti-inflammatory medications, corticosteroid injections, and two different courses of viscosupplementation injections. On physical exam, the patient has a moderate effusion and is tender to palpation at the medial and lateral joint lines with range of motion of 0-120 degrees. She is stable to varus and valgus stress with good range of motion of the hip. Pre-operative radiographs demonstrate moderate degenerative changes with osteophyte formation, subchondral sclerosis, and joint space narrowing (figure 7).

After a thorough discussion of risks, benefits, and alternatives, the patient elected to proceed with a total knee arthroplasty using the MAKO robotic system. At the latest two year follow-up, she was "thrilled" with her recovery and her pain had completely resolved. Radiographs at this appointment demonstrate a well-fixed, press-fit total knee prosthesis without component loosening, subsidence, or migration (figure 8).

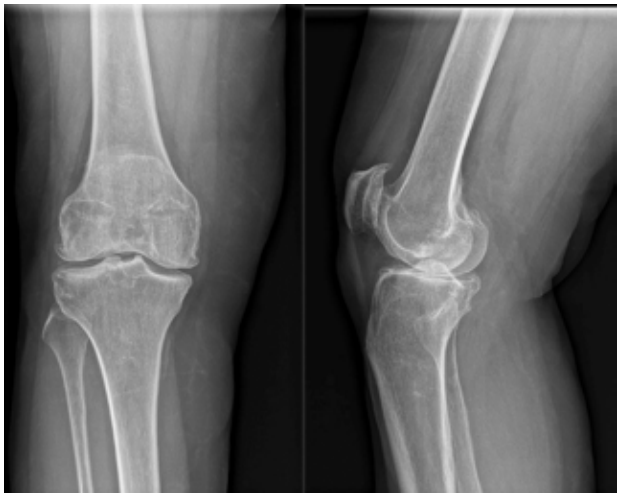

Figure 7. Pre-operative right knee radiographs demonstrating Kellgren-Lawrence stage 3 osteoarthritis.

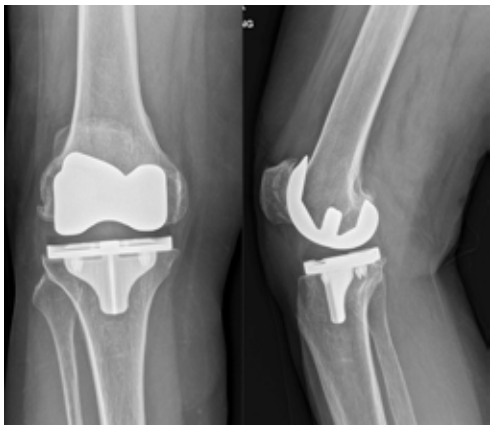

Figure 8. Post-operative right knee radiographs demonstrating a right knee total knee prosthesis in normal alignment without evidence of loosening, subsidence, or migration.

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