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Mako Total Knee arthroplasty: clinical summary

Mako clinical evidence

Volume 4

1. Introduction

Total knee arthroplasty (TKA) is an established and successful procedure for the treatment of end-stage knee arthritis.[1] Survivorship at ten years is commonly reported in the 90th percentile,[2] while outcomes reported using Patient-Reported Outcome Measures (PROMS) demonstrate that TKA also delivers a functional benefit to patients.[3]

Despite the demonstrable benefits of TKA, satisfaction rates are known to be lower than for total hip arthroplasty.[4] Reported dissatisfaction rates for TKA are around 20%.[5-6] TKA is also known to be sensitive to surgical factors such as implant positioning and soft tissue balance.[7,8] Inaccuracies in positioning and soft tissue balance have the potential to reduce implant survivorship and impact negatively on patient outcomes.[7-9]

The Mako Total Knee application, in comparison to manual techniques, has been shown in a cadaveric and clinical setting to have increased accuracy and precision of component placement to plan.[10,13] These achievements were accomplished, in part, by preoperative three-dimensional planning, which takes into account each patient's specific anatomy. This plan can be virtually modified intra-operatively to address implant alignment, soft tissue balancing, and flexion contractures. Additional features include intra-operative visual, auditory, and tactile feedback to the user. The robotic-arm assisted technology also has an auto switch-off option that prevents the sawblade from cutting outside the designated surgical field.

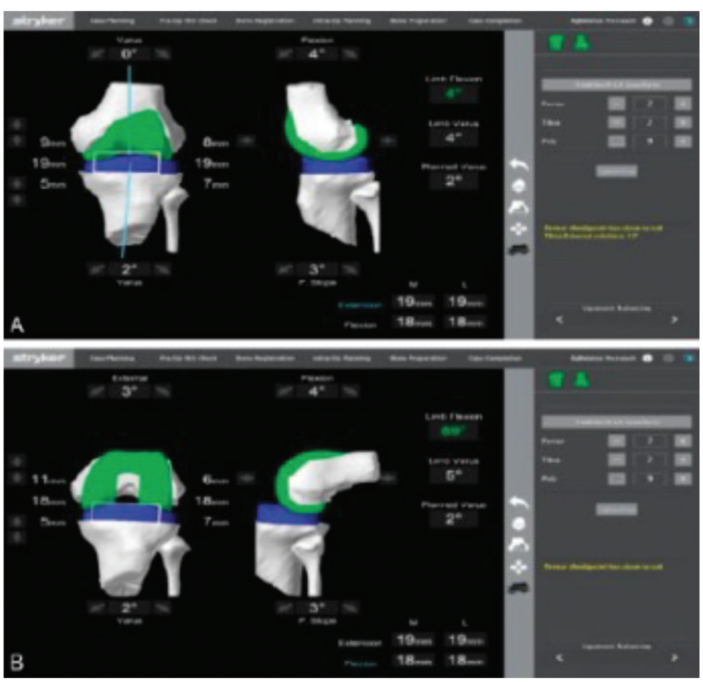

Figure 1. Knee (A) extension and (B) flexion final implant planning; 100% of patients achieved a post-bone cut extension gap difference between -1 and 1mm (mean, -0.1mm) and 99% of patients achieved a post-bone cut flexion gap difference of between -2mm and 2mm (mean, 0mm).[12]

This document summarizes the evidence to date supporting the use of robotic-arm assisted technology during TKA.

2. What is the evidence to support the science behind Mako Total Knee?

Over all, robotic-arm assisted technology offers the potential to enhance TKA through a combination of pre-operative planning,[11] intra-operative adjustments,[12] and guided bone resections.[13,15] Several studies have demonstrated the efficiency of 3D planning,[11] the benefits of intra-operative joint balancing,[12] and the potential for soft tissue protection.[14-15] Robotic-arm assisted total knee arthroplasty (RATKA) has also been found to reduce surgical variability among surgeons early in their surgical experience.[16]

2.1 Accuracy and precision

A patient's unique anatomy and disease state can vary significantly, creating operative case complexity for the surgeon. Robotic-arm assisted technology enables the surgeon to make intra-operative decisions based on pre-operative planning, which is carried out utilizing computed tomography (CT). An intra-operative feedback loop allows for implant placement adjustments which helps surgeons determine joint balancing based on soft tissue feedback, prior to making any bone cuts. Marchand et al. (2018) considered intra-operative balancing and resection data for 335 patients who underwent Mako Total Knee.[12] Pre-operative plans were adjusted to achieve balance, defined as having a medial and lateral flexion gap difference within 2mm. Regardless of disease state or types of deformities, all patients achieved a post-bone cut extension gap difference of between -1 and 1mm (mean, -0.1mm) and 99% of patients achieved a post-bone cut flexion gap difference of between -2mm and 2mm (mean, 0mm) (Figure 1). Additionally, there were no final minor soft-tissue releases because all knees were balanced prior to bone cuts, and there were no further changes during trial stage. The capacity to visualize changes in joint balancing and adjust component position prior to bone cuts allowed the surgeon to adopt a balancing resection technique associated with robotic-arm assisted surgery.

The ability to pre-operatively plan can assist in selecting appropriately sized implants,[17] a factor which is critical to the success of TKA.[18] Robotic-arm assisted technology requires the use of a pre-operative CT that is used to perform 3D templating. In a study performed by Bhimani et al. (2017), 54 consecutive patients underwent unilateral Mako Total Knee.[11] Three-dimensional planning software specific to the Mako System was used to provide an initial pre-operative implant plan which was then updated intra-operatively, based on risk of anterior femoral notching. This minimized medial and lateral overhang of the tibial and femoral implants, and maximized tibial cortical contact. The software predicted component size exactly in 96% of femoral implants and 89% of tibial baseplates. In comparison, studies comprising a 2D technique predicted the correct implant size in 43.6% to 68% of cases.[11] For the 3D technique, all disparities between the predicted and actual tibial sizes were due to the presence of osteophytes.[11] One hundred percent of the actual tibial baseplates and femoral implants used were within one size of the pre-operatively predicted size. There were no cases of femoral notching or of medial or lateral implant overhang on the femoral or tibial sides.

While manual TKA has demonstrated clinical success,[19] a meta-analysis of component alignment found mechanical axis malalignment of greater than 3° in 9.0% of computer-assisted (CAS) and 31.8% of manual TKA (MTKA) surgeries.[20] In a cadaveric study, a high volume surgeon with no prior clinical robotic experience performed a matched pair comparison of MTKA to RATKA on 6 specimens (12 knees).[21] A learning curve was considered and the first three specimens were eliminated from comparison. The last three RATKA and MTKA matched pairs found that RATKA demonstrated greater accuracy and precision of bone cuts and component placement to plan compared to MTKA (Figure 2). On average, RATKA (n=6) final bone cuts and final component positions were 5.0 and 3.1 times more precise to plan than the MTKA control, retrospectively. Furthermore, RATKA has the potential to increase both the accuracy and precision of bone cuts and implant positioning to plan for an experienced manual surgeon who is new to RATKA.

The ability to effectively align components during TKA is key to implant function and survivorship.[22,23] A prospective, multi-surgeon study was performed at the Hospital of Special Surgery in New York City to assess implant placement accuracy in a clinical setting.[13] Data was reviewed for 105 patients who underwent Mako Total Knee, all of whom had received hip-to-ankle standing biplanar EOS radiographs pre-operatively and 1 year post-operatively. Independently, two fellowship-trained arthroplasty surgeons measured coronal and sagittal alignment of the tibial component and coronal alignment of the femoral component relative to the mechanical axis of the limb, on the 1-year postoperative radiographs. These values were then compared to the final intra-operative plan and for inter-observer reliability. The pre-operative template component size was 100% accurate for both components. The absolute mean deviation in post-operative coronal alignment compared to intra-operative alignment was 0.625±0.70° and 0.45 ±0.50° for the tibia and femur, respectively. The absolute mean change in post-operative tibial sagittal alignment was 0.47±0.76° and inter-observer reliability was significant between both observers ($p<0.05$). The haptically-guided Mako Total Knee demonstrated high reliability and accuracy of coronal tibial, coronal femoral, and tibial sagittal alignment when comparing the executed intra-operative plan at 1-year post-operative via biplanar hip-to-ankle radiographs.

2.2 Soft tissue protection

A cadaveric study was performed to determine the benefits of soft tissue protection by examining damage to 14 soft tissue structures, including the deep medial collateral ligament (dMCL), posterior cruciate ligament (PCL), popliteus, iliotibial band (ITB), and patellar ligament, following Mako Total Knee (or robotic-arm assisted TKA, RATKA) and MTKA.[14] A total of 24 paired cadaveric knees (12 RATKA and 12 MTKA) were prepared by four surgeons. An additional two surgeons, blinded to the method of preparation, graded structure

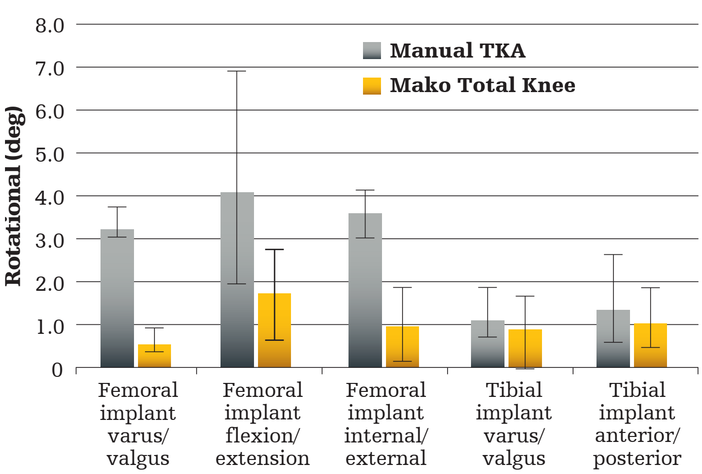

Figure 2. A learning curve was considered for the cadaveric accuracy study and the first three specimens were eliminated from comparison. The last three RATKA (Mako Total Knee) and MTKA matched pairs showed that RATKA demonstrated greater accuracy and precision of bone cuts and component placement to plan compared to MTKA.[21]

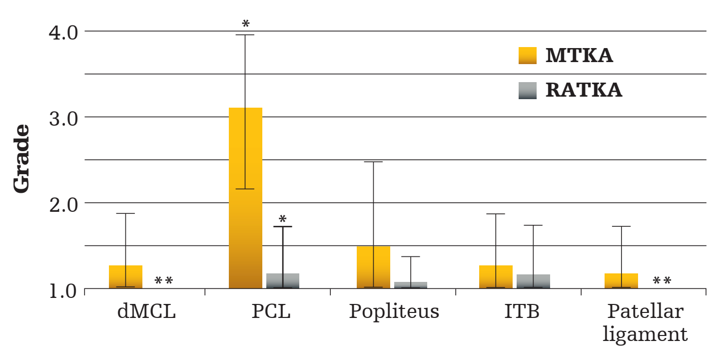

Figure 3. Iatrogenic soft-tissue damage was assessed and graded 1-4, where higher numerical values represent higher levels of damage. Average grade values are shown for extent of damage to the dMCL, PCL, popliteus, ITB, and patellar ligament in MTKA and RATKA specimens. Error bars indicate standard deviations. *PCL showed significant difference ($p<0.05$); **Grade average ± standard deviation for dMCL and patellar ligament was 1±0.[14]

damage using direct visual grading and arthroscopic imaging. No intentional soft tissue releases were performed in either group to balance the knee. Grading of soft tissue damage post-operatively) determined that significantly less damage occurred to the PCL in the haptic-controlled RATKA than in MTKA specimens (p=0.004) (Figure 3). RATKA specimens also experienced less damage to the dMCL (p=0.186), ITB (p=0.5), popliteus (p=0.137), and patellar ligament (p=0.5). It was concluded that these findings can potentially be attributed to RATKA using a stereotactic boundary to constrain the sawblade, which can prevent unwanted soft-tissue damage.

Assessment of iatrogenic bone and soft tissue injury was continued by Kayani et al. (2018) in a clinical setting.[15] This study comprised a prospective cohort of 30 consecutive MTKAs followed by 30 consecutive Mako Total Knees. All surgeries were performed by a single surgeon and both groups were prepared for a posterior stabilized prosthesis. Intra-operative photographs of the femur, tibia, and periarticular soft tissues were taken before implantation of the prostheses. A macroscopic soft tissue injury (MASTI) classification system was developed to grade iatrogenic bone and soft tissue injuries. Assessment of images indicated that patients undergoing Mako Total Knee had reduced medial soft tissue injury in both passively correctible ($p<0.05$) and non-correctible varus deformities ($p<0.05$); more pristine femoral ($p<0.05$) and tibial ($p<0.05$) bone resection cuts; and, improved MASTI scores compared to conventional TKA ($p<0.05$). Findings from this study were in keeping with the previous cadaveric study.[14] Kayani et al. (2018) reported soft tissue trauma that may be considered subtle subclinical findings, but also mentioned previous studies that have shown even limited soft tissue releases may promote changes in local and systemic inflammatory responses, leading to increased pain and delayed post-operative rehabilitation.[15] Further studies are necessary to determine if the observed periarticular injury will have an impact on systemic inflammatory response and post-operative patient pain.

2.3 Reduced surgical variability

Hampp et al. (2018) studied two surgeons undergoing orthopaedic fellowship training to better understand how a robotics system can affect surgeon variability and mental exertion when performing TKA.[16] Each surgeon prepared six cadaveric legs for cruciate retaining TKA, with MTKA on one side (3 knees) and Mako Total Knee on the other (3 knees), and under the instruction to execute a full TKA procedure through trialling to achieve a balanced knee. Assessment of the final procedure indicated that robotic technology reduced variability of the TKA procedure. The Mako Total Knee cases were more likely use the minimum poly thickness of 9mm, required less post-resection recuts to achieve a balanced knee, had a greater perceived planarity, and the surgeons were more likely to recommend using a cementless implant. Additionally, the operating surgeons reported reduced mental effort when performing bone measurements, tibial bone cutting, knee balancing, trialling, and post-resection adjustments with Mako Total Knee compared to MTKA. Results indicated that the pre-planning and execution of the robotic system, were useful in reducing surgical variability and mental exertion for surgeons early in their surgical experience.

3. The adoption of Mako Total Knee in the operating room

Although there are clear benefits to adopting robotic-arm assisted technology,[11-13,15,24-26] studies have shown a learning curve associated with Mako Total Knee before a surgical team can become time neutral to their operative time when performing manual TKA.[27] One surgical group has quantified this learning curve to likely take between 10 and 15 cases, regardless of the level of experience of the surgeon.[28] In an intraoperative study, the use of Mako Total Knee was associated with increased energy expenditure from the surgeon, but with one less operating room assistant involved than for a manual procedure.[29] Research in a cadaveric lab setting, found that robotic-arm assisted technology resulted in a reduced risk of neck injury and increased satisfaction for the surgeon.[30] Furthermore, based on data from another cadaveric lab, a surgical assistant had reduced ergonomic risk as they were no longer required to participate in instrument placement and had reduced participation in soft tissue retraction throughout the procedure.[31]

3.1 Surgical team learning curve

As with most new surgical techniques, there is a learning curve associated with RATKA. Sodhi et al. (2017) performed a study to assess this learning curve, in which two surgeons performed a total of 240 robotic-arm assisted cases.[27] Each case was allocated to a group of 20 sequential cases and a learning curve was created based on mean operative times. These times were compared to mean operative times for 20 randomly selected manual cases performed by the same surgeon. Figure 4 provides surgical times for both surgeons. For Surgeon 1, mean operative time between the first and last cohorts was reduced from 81 minutes to 70 minutes ($p<0.05$. For Surgeon 2, mean operative time between the first and last cohort was reduced from 117 minutes to 98 minutes ($p<0.05$). For both surgeons, the final 20-case set was time-neutral to their manual cohort. This data implies that within a few months, a surgeon should be able to adequately perform RATKA without any added operative time.[27]

In a separate learning curve study, Fleischman et al. (2018) followed a separate group of two surgeons with differing levels of TKA experience.[28] Each surgeon performed a minimum of 20 Mako Total Knee cases (n=45) and the times required to perform specific tasks were compared to conventional TKA cases (n=48) from the same period. Time points measured included: (1) tracker placement (pin time); (2) landmarks and anatomic registration (registration time); (3) bone preparation and cutting (cutting time); and, (4) ligament balancing and implant trialing (trialing time), where pin time and registration time were specific to the Mako Total Knee application. A mean arthroplasty time of 24.9 minutes was measured for RATKA, which was a 22.8-minute reduction in time from the first three Mako Total Knee cases. There was a 4.2-minute reduction in mean pin time, 5.3-minute reduction in mean registration time, 5.8-minute reduction in cutting time, and a 7.3-minute reduction in mean trialing time. It was concluded that surgeons completed their learning curve within their first 10-15 cases, regardless of surgical experience.

3.2 Surgical team usability

Recent studies have focused on understanding how Mako Total Knee impacts the patient,[13-14] while less is known about the ways in which this technology affects the surgeon. TKA has been shown to be a highly demanding procedure for surgeons, requiring on average 320 kcal/hour.[32] Performing multiple surgeries per day with this energy expenditure can lead to fatigue and exhaustion. Subsequently, Blevins et al. (2018) identified the need to conduct an intra-operative study to assess how the use of robotic technology can influence energy expenditure.[29] This study evaluated two specialized arthroplasty

Surgical time to perform robotic-arm assisted TKA versus manual TKA

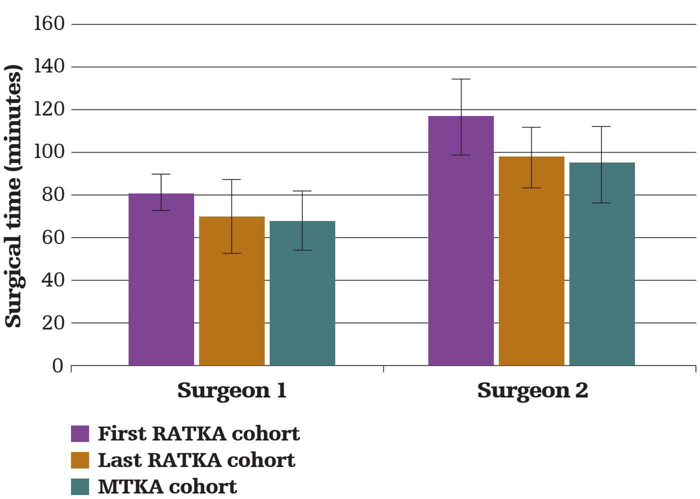

Figure 4. Mean surgical time data for RATKA and MTKA indicate that within a few months, a surgeon should be able to perform RATKA without any added operative time. For both surgeons, mean surgical time was greatest for the first cohort of 20 RATKA cases when compared to the last cohort of 20 patients. The last cohort of 20 RATKA cases were time neutral to the surgeons' 20 MTKA cases.[27]

surgeons, one of whom was a high volume 'veteran' surgeon (HV) and the other a lower volume, less experienced surgeon (LV). Each surgeon wore biometric-enabled shirts that collected data on energy expenditure, including total caloric expenditure, kilocalories per minute, heart rate variability, and surgical duration, as they performed 35 conventional and 29 Mako Total Knee procedures. For both surgeons, Mako cases took longer and increased the surgeons' total energy expenditure. However, the Mako cases also required one less operating room assistant, reducing the total staff requirement for the procedure. It was also found that surgical experience in TKA influenced a surgeon's energy expenditure. The study concluded, it is possible that more experience with using the Mako Total Knee application could create efficiencies over time that may also reduce energy expenditure.

Aside from energy expenditure, orthopaedic surgery can also be a demanding procedure on a surgeon's musculoskeletal health, with studies having reported that 44-66% of surgeons surveyed have experienced a work-related injury, with 10-27% requiring surgery.[33-34] Of these, neck injuries typically have one of the highest incidences.[33-34] An ergonomic assessment was performed by Scholl et al. (2018) to establish how the use of robotic technology implemented during TKA procedures might influence a surgeon's cervical posture, as well as overall surgeon satisfaction.[30] A cadaveric assessment was performed with two high-volume surgeons, each performing three MTKA and three Mako Total Knee cases. Kinematic sensors were used to assess mean head (occiput) and neck flexion angles, and following each surgical case the surgeons were asked a series of questions to assess their overall satisfaction. Mean head (occiput) flexion angle for MTKA was higher than that measured for Mako Total Knee cases (28° vs 18°, respectively). Additionally, surgeons reported higher satisfaction when performing Mako Total Knee compared to MTKA. Based on this limited sample size, it was concluded that robotic technology has the potential to increase surgeon satisfaction and reduce the risk of mechanical trauma to the surgeon.

Similarly to surgeons, surgical assistants routinely take on ergonomically challenging tasks, specifically during tasks such as retracting soft tissue, transferring instrument sets, and setting up surgical tables.[35,36] Scholl et al. (2018) performed an additional assessment to examine an operating room surgical assistant's posture while assisting with MTKA and Mako Total Knee.[31] Kinematic sensors were used to monitor shoulder and lower back movement as the surgical assistant helped with three MTKA and three Mako Total Knee procedures.[31] The role of the surgical assistant was to assist the surgeon with soft tissue retraction, instrument placement, removal of cut bone, and to help hand instruments to the surgeon. For all MTKA procedures, the surgical assistant had the highest kinematic scores during bone cutting and instrument placement. Kinematic scores improved for Mako Total Knee procedures since the surgical assistant had limited participation during bone cutting and there was no need to assist with manual instrument placement. Results from this study indicate that Mako Total Knee may reduce ergonomic risks to surgical assistants during TKA, with the authors attributing this reduced risk primarily to the assistant no longer needing to participate in instrument placement and reduced participation in soft-tissue retraction throughout.

4. What are the clinical outcomes of Mako Total Knee?

The Mako Total Knee application was launched in June 2016. As the initial Mako Total Knee patients begin to reach post-operative time points, publications reporting on early clinical outcomes have become available. Marchand et al. (2017) published findings from a single-surgeon study that was performed on 20 consecutive cemented Mako Total Knee patients matched with 20 consecutive cemented MTKA patients.[24] A Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) survey, including pain, stiffness, and physical function subcategories, was administered to patients at their 6 month post-operative visit. The Mako Total Knee cohort demonstrated statistically significant lower mean pain scores ($p<0.05$), better overall physical function scores statistically significant, and greater patient satisfaction and clinical outcomes. These results indicate the potential of this surgical tool to improve short-term pain, physical function, and total satisfaction scores. Although this study involved a limited cohort, it showed promising short-term outcomes for Mako Total Knee patients when compared to the MTKA control group (Figure 5).

In another study of early clinical outcomes, Clark (2017) presented results from 50 MTKA cases compared to 90 Mako Total Knee cases, all performed by the presenting surgeon.[25] Three months post-operatively, a Forgotten Joint Score (FJS) was provided to study participants, with results indicating a significantly lower FJS for the Mako Total Knee (36.24 ± 6.51) cohort than for the MTKA cohort (45.70 ± 8.15). This indicates that, at early follow-up, the Mako Total Knee patients were less aware of their previously problematic knee during their daily activities.

In a large, single-surgeon study, Marchand et al. (2018) considered patient-focused hospital metrics for 335 Mako Total Knee patients.[12] This study set included 158 left knees and 177 right knees in patients with a mean age of 67 years and mean body mass index of 30 kg/m^2. Patient average length of stay was 2 days and 2.2% of patients had a readmission. Also, none of the readmissions were Mako System-related. For this patient group, there were no reported surgical site infections, pin site fractures, or adverse events due to soft tissue damage, and no conversions from a Mako Total Knee case to a MTKA case intra-operatively.[12]

In a prospective, consecutive series, single-surgeon study, Kayani et al. (2018) demonstrated statistically significant early postoperative results for 40 patients who received Mako Total Knee Surgery as compared to 40 patients who received conventional jig-based TKA.[26] The Mako Total Knee group had less post-operative pain ($p<0.001$), less need for analgesics ($p<0.001$), less post-operative blood loss ($p<0.001$), less time to achieve straight leg raise ($p<0.001$), less time to hospital discharge (Mako Total Knee resulted in 26% reduction in length of stay), and improved maximum flexion at discharge.[26] In summary this study was associated with decreased pain, improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based TKA.[26] It is important to also note that this study did not undertake a financial analysis. As a result, financial implications cannot be assumed at this time.

As the initial group of Mako Total Knee patients reach 1-year follow-up, studies are beginning to report on these outcomes. In a prospective, multi-surgeon study comprising 105 patients, Carroll et al. (2018) assessed patient satisfaction and outcomes for Mako Total Knee at 1-year follow-up.[13] Patients were asked to complete Levels of Emotional Awareness Score (LEAS), Numeric Pain Rating Scale (NPRS), and Knee Injury and Osteoarthritis Score Junior (KOOS Jr). All scores showed statistically

Six-month manual versus robotic TKA WOMAC scores

Surgical technique	Manual TKA	Robotic-arm assisted TKA	*p*=value
Mean 6-mo postoperative WOMAC – pain	5±3 (range 0-10)	3+3 (range 0-8)	< 0.05
Mean 6-mo postoperative WOMAC – physical function	9±5 (range 0-17)	4+5 (range 0-14)	0.055
Mean 6-mo postoperative WOMAC – total score	14 (range 0-27, SD±8)	7 (0-22); SD:+8	< 0.05

Abbreviations: SD, standard deviation; TKA, total knee arthroplasty; WOMAC, Western Ontario and McMaster Universities Arthritis Index.

Figure 5. Six-month manual versus robotic TKA WOMAC scores[24]

significant (P<0.05) improvement from pre-operative to one-year post-operative assessments: LEAS improved from 8 to 10, NPRS from 8 to 1, and KOOS Jr from 78 to 84.6. Patients also reported high subjective clinical outcome score improvement one year post-operatively.[13]

The Mako Total Knee technology allows a surgeon to pre-operatively plan a case based on a patient CT as well as intra-operatively adjust that plan based on soft tissue laxity, all prior to making a single bone cut. These features can be beneficial when a patient presents with severe varus/valgus deformities or flexion contractures. In addition to early patient outcomes, Marchand et al. (2017) have also published a case series demonstrating how the Mako System can correct severe deformities.[37] Three case studies were presented, in which the use of the robotic-arm assisted system allowed the surgeon to achieve desired alignment restoration for patients with severe deformities (Figure 6).

5. How has Mako Total Knee affected episode-of-care costs?

Mako Total Knee provides surgeons with pre-operative planning and real-time data, allowing for continuous assessment of ligamentous tension and range-of-motion. Using this technology, soft tissue protection,[14,15] reduced early post-operative pain,[26] and improved patient satisfaction[37] have been shown. As Mako Technology continues to be adopted, it will also be important to understand if Mako Total Knee can reduce episode-of-care (EOC) costs.

Baker Tilly, a third party consulting company, performed a retrospective review at the request of Stryker, of a US-based payer commercial database for TKA surgeries performed between January 2016 and March 2017.[38] After propensity score matching, 519 Mako Total Knee and 2,595 MTKA cases were assessed to compare EOC cost, index cost, Length of Stay (LOS), discharge disposition, and readmission rates. Results showed that 90-day EOC costs were $2,391 less for Mako patients ($p<0.0001$) than for MTKA patients. Index facility cost and LOS were also less for Mako patients by $640 ($p=0.0001$) and 0.7 days ($p<0.0001$), respectively. Additionally, Mako patients were discharged to self-care more frequently (56.65% Mako vs. 46.67% MTKA, $p<0.0001$) and Skilled Nursing Facilities less frequently (12.52% Mako vs. 21.70% MTKA, $p<0.0001$). RATKA patients had a 90-day readmission reduction of 33% ($p=0.04$) over MTKA patients. This evidence indicates potential cost savings when performing Mako versus MTKA. The 90-day EOC savings for the Mako group were driven by reduced facility costs, LOS, readmissions, and an economically beneficial discharge destination.[38] Although this data is compelling, it must be understood that cost-effectiveness data may differentiate across regions due to different healthcare and hospital systems, treatment plans and associated costs.

6. Conclusion

In conclusion, the Mako Total Knee application has been shown in a single-centre, multi-surgeon study, to be able to place implants accurately to plan.[13] In a separate cadaveric and clinical study, soft tissue damage was shown to be reduced when compared to manual TKA surgery.[14,15] Transitioning to new technology is potentially demanding for any operating room, however, two surgeons with different levels of TKA experience were able to have Mako procedure times reach a steady state in 10 to 15 cases.[28] In a cadaveric study model, surgeon and surgical assistant ergonomics were improved by use of robotic-arm assisted techology.[30,31]

In a prospective, consecutive series, single-surgeon study, early post-operative pain and blood loss were shown to be reduced in Mako Total Knee when compared to manual surgery.[26] Multiple studies have shown early outcomes measured using PROMs to be positive,[13,24-26] although longer term follow-up is on-going.

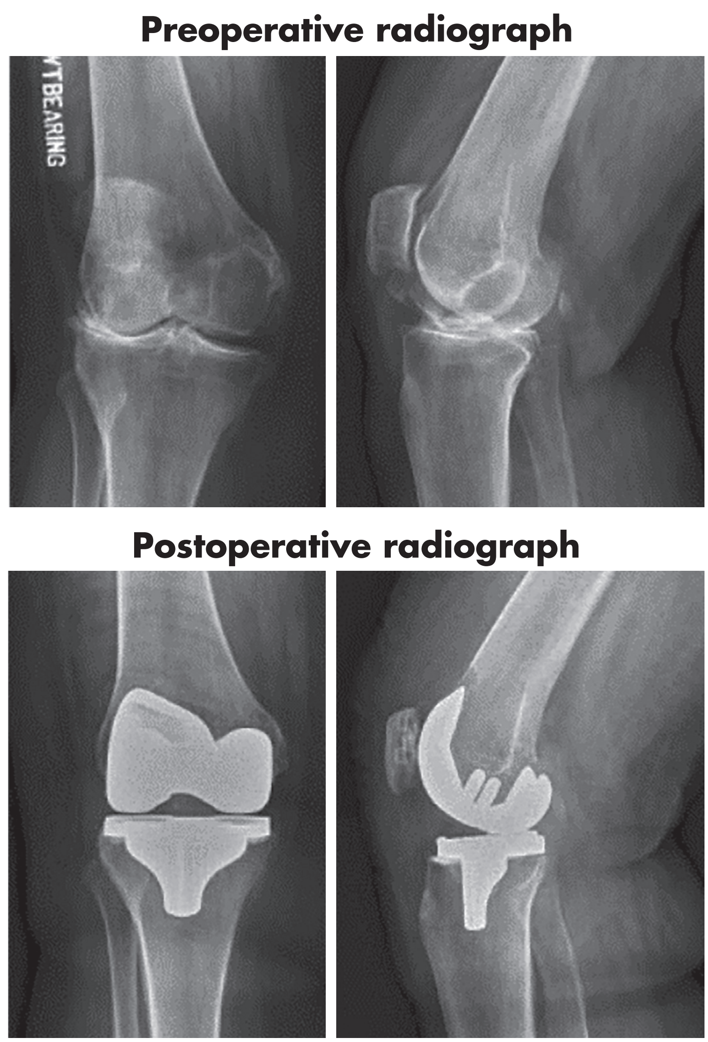

Figure 6. Pre-operatively, there was a 9-degree valgus deformity in extension. Intra-operative balancing and realignment were performed and the final coronal alignment was 1-degree valgus. For this case, no soft tissue releases were needed.[37]

References

1. Hamilton, D.F., Burnett, R., Howie, C.R., Patton, J.T., Moran, M., Simpson, A.H., Gaston, P. Implant design influences patient outcome after total knee arthroplasty: a prospective double-blind randomised controlled trial. Bone Joint J 2015;97-B:64–70.
2. Mistry, J.B., Elmallah, R.K., Chughtai, M., Oktem, M., Harwin, S.F., Mont, M.A. Long-Term Survivorship and Clinical Outcomes of a Single Radius Total Knee Arthroplasty. Surgical Technology International XXVIII.
3. Scott, C.E.H., Clement, N.D., MacDonald, D.J., Hamilton, D.F., Gaston, P., Howie, C.R., Burnett, R. Five-year survivorship and patient-reported outcome of the Triathlon single-radius total knee arthroplasty Knee Surgery, Sports Traumatology, Arthroscopy 2015;23(6):1676-8.
4. Wylde, V., Blom, A.W., Whitehouse, S.L., Taylor, A.H., Pattison, G.T., Bannister, G.C. Patient-Reported Outcomes After Total Hip and Knee Arthroplasty: Comparison of Midterm Results. JOA 2009;24(2):210-16
5. Bourne, R.B., Chesworth, B.M., Davis, A.M., Mahomed, N.N., Charron, K.D.J. Patient Satisfaction after Total Knee Arthroplasty: Who is Satisfied and Who is Not? CORR 2010;468: 57–63.
6. Noble P.C., Conditt, M.A., Cook, K.F., Mathis, K.B. Patient Expectations Affect Satisfaction with Total Knee Arthroplasty. CORR 2006;453: 35–43.
7. McNabb, D.C., Kim, R.H., Springer, B.D. Instability after total knee arthroplasty. J Knee Surg 2015; 28:97–104. doi:10.1055/s-0034-1396080.
8. Kim, Y-H., Park, J-W., Kim, J-S., Park, S-D. The relationship between the survival of total knee arthroplasty and postoperative coronal, sagittal and rotational alignment of knee prosthesis. Int Orthop 2014; 38:379–85. doi:10.1007/s00264-013-2097-9.
9. Mason, J.B., Fehring, T.K., Estok, R., Banel, D., Fahrbach, K. Meta-analysis of alignment outcomes in computer-assisted total knee arthroplasty surgery. J Arthroplasty 2007;22(8):1097–106. doi:10.1016/j.arth.2007.08.001.
10. Khlopas, A., Sodhi, N., Sultan, A.A., Chughtai, M., Molloy, R.M., Mont, M.A. Robotic Arm-Assisted Total Knee Arthroplasty. The Journal of Arthroplasty 2018; doi: 10.1016/j.arth.2018.01.060.
11. Bhimani, S., Bhimani, R., Feher, A., Malkani, A. Accuracy of preoperative implant sizing using 3D preplanning software for robotic-assisted total knee arthroplasty. AAHKS 2017 Annual Meeting. 2-5 Nov 2017. Dallas, TX.
12. Marchand, R.C., Sodhi, N., Bhowmik-Stoker, M., Scholl, L., Condrey, C., Khlopas, A., Sultan, A.A., Newman, J.M., Mont, M.A. Does the Robotic Arm and Preoperative CT Planning Help with 3D Intraoperative Total Knee Arthroplasty Planning? J Knee Surg. 2018.
13. Carroll, K., Nickel, B., Pearle, A., Kleeblad, L.J., Mayman, D.J., Jerabek, S.A., Small Radiographic and Functional Outcomes of Robotic-Assisted Total Knee Arthroplasty at One Year ISTA 31st Annual Congress to be held 10-13 October, 2018.
14. Hampp, E.L., Scholl, L.Y., Faizan, A., Westrich, G., Mont, M.A. Greater iatrogenic soft tissue damage in conventional approach when compared with the robotic-arm assisted approach for total knee arthroplasty. EFORT 2018 Annual Meeting, Barcelona, Spain. Poster No. 1582. May 30 – June 1, 2018.
15. Kayani, B., Konan, S., Pietrziek, J., Haddad, F. S. Iatrogenic Bone and Soft Tissue Trauma in Robotic-Arm Assisted Total Knee Arthroplasty Compared with Conventional Jig-Based Total Knee Arthroplasty: A Prospective Cohort Study and Validation of a New Classification System. The Journal of Arthroplasty 2018.
16. Hampp, E.L., Scholl, L.Y., Westrich, G., Mont, M.A. Can the use of robotic technology reduce surgical variability and mental exertion when performing total knee arthroplasty? ISTA 31st Annual Congress. 10-13 October, 2018.
17. Gonzalez, M.H., Mekhali, A.O. The failed total knee arthroplasty: evaluation and etiology. J Am Acad Orthop Surg. 2004;12(6):436-46.
18. Hernandez-Vaquero D., Abat, F., Sarasquete, J., Monllao, J.C. Reliability of preoperative measurement with standardized templating in total knee arthroplasty. World J Orthop, 2013;4(4):287-90.
19. National Joint Registry (NJR) for England, Wales, Northern Ireland and the Isle of Man. 13th Annual Report. Available at: http://www.njrreports.org.uk/Portals/0/PDFdownloads/NJR%2013th%20Annual%20Report%202016.pdf 2016. Accessed Dec. 10, 2017.
20. Mason J.B., Fehring, T.K., Estok, R., Banel, D., Fahrbach, K. Meta-analysis of alignment outcomes in computer-assisted total knee arthroplasty surgery. J Arthroplasty. 2007;22(8):1097-106.
21. Hampp, EL., Chughtai, M., Scholl, L.Y., Sodhi ,N., Bhowmik-Stoker, M., Jacofsky, D.J., Mont, M.A. Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared to manual technique. J Knee Surg. 2018.
22. Ritter, M.A., Faris, P.M., Keating, E.M., Meding, J.B. Postoperative alignment of total knee replacement. Its effect on survival. Clin Orthop Relat Res. 1994; 299:153-6.
23. Wasielewski, R.C., Galante, J.O., Leighty, R.M., Natarajan, R.N., Rosenberg, A.G. Wear patterns on retrieved polyethylene tibial inserts and their relationship to technical considerations during total knee arthroplasty. Clin Orthop Relat Res. 1994; 299:31-43.
24. Marchand, R.C., Sodhi, N., Khlopas, A., Sultan, A.A., Harwin, S.F., Malkani, A.L., Mont, M.M. Patient satisfaction outcomes after robotic-arm assisted total knee arthroplasty: a short-term evaluation. J Knee Surg. 2017;30(9): 849-853.
25. Clark, G. Australian Experience Mako Robotic TKA. AOA Annual Meeting, Oct 8-12, 2017, Adelaide.
26. Kayani, B., Konan, S., Tahmassebi, J., Pietrzak, J.R.T., Haddad, F.S. Robotic-arm assisted total knee arthroplasty is associated with improved early functional recovery and reduced time to hospital discharge compared with conventional jig-based total knee arthroplasty: A prospective cohort study. Bone and Joint Journal: 2018;100-B:930–7.
27. Sodhi, N., Khlopas, A., Piuzzi, N.S., Sultan, A.A., Marchand, R.C., Malkani, A.L., Mont, M.A. The learning curve associated with robotic total knee arthroplasty. J Knee Surg. 2017.
28. Fleischman, A.N., Lutz, R.W., Vahedi, H., Orozco, F., Hozack, W.J., Chen, A.F. Time-related learning curve of robotic-arm assisted total knee arthroplasty. AAOS Poster No. 5373. New Orleans, LA. 8 March 2018.
29. Blevins, K.M., Danoff, J.R., Goel, R., Foltz, C., Hozack, W.J., Chen, A.F. Energy expenditure during conventional and robotic arm-assisted total knee arthroplasty. ISTA 31st Annual Congress to be held 10-13 October, 2018.
30. Scholl, L.Y., Hampp, E.L., Alipit, V., Bhave, A., Bhowmik-Stoker, M., Mont, M.A., Chen, A. Does the use of Robotic Technology Improve a Surgeon's Cervical Ergonomics and their Overall Satisfaction? ISTA 31st Annual Congress to be held 10-13 October, 2018.
31. Scholl, L.Y., Hampp, E.L., Alipit, V., Bhave, A., Bhowmik-Stoker, M., Mont, M.A., Chen, A. Can Surgical Technology Reduce Surgical Staff Postural Demands during Total Knee Arthroplasty? ISTA 31st Annual Congress to be held 10-13 October, 2018.
32. Sharkey, P.F., Danoff, J.R., Klein, G., Parvizi, J. Surgeon Energy Expenditure During Total Joint Arthroplasty. J Arthroplasty 2007;22(2):210–2.
33. Alqahtani, S.M., Alzahrani, M.M., Tanzer, M. Adult reconstructive surgery: a high-risk profession for work-related injuries. J Arthroplasty 2016;31(6):1194-8.
34. Davis, W.T., Sathiyakumar, V., Jahangir, A.A., Obremskey, W.T., Sethi, M.K. Occupational injury among orthopaedic surgeons. J Bone Joint Surg Am. 2013;95(15): e107.
35. OR Manager monthly publication. New research looks at ergonomic stresses on operating room staff. 2005, Jul;21(7):6-8.
36. Abdollahzade, F., Mohammadi, F., Dianat, I., Asghari, E., Asghari-Jafarabadi, M., Sokhanvar, Z. Working posture and its predictors in hospital operating room nurses. Health Promot Perspect. 2016 ;6(1):17-22.
37. Marchand, R.C., Khlopas, A., Sodhi, N., Condrey, C., Piuzzi, N.S., Patel, R., Delanois, R.E., Mont, M.A. Difficult cases in robotic-arm assisted total knee arthroplasty: a case series. J Knee Surg. 2017 [Epub ahead of print].
38. Cool, C.L., Needham, K., Mont, M.A., Jacofsky, D.J. A 90 day episode of care cost analysis of robotic assisted total knee arthroplasty. The Knee Society Meeting. New York, NY. September 20-22, 2018.

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