Published online: 15.11.2019

Improved Patient Satisfaction Following Robotic-Assisted Total Knee Arthroplasty

Austin F. Smith, MD[1] Christian J. Eccles, MD[1] Samrath J. Bhimani, MD[1] Kevin M. Denehy, MD[1] Rohat B. Bhimani, BA[2] Langan S. Smith, BS[3] Arthur L. Malkani, MD[4]

[1] Department of Orthopaedic Surgery, University of Louisville, Louisville, Kentucky
[2] Feinberg School of Medicine, Northwestern University, Chicago, Illinois
[3] Orthopedic Associates, Kentucky One Health Medical Group, Louisville, Kentucky
[4] Adult Reconstruction Program, Kentucky One Health, University of Louisville, Louisville, Kentucky

Address for correspondence Arthur Malkani, MD, Adult Reconstruction Program, Kentucky One Health, University of Louisville, 201 Abraham Flexner Way, Ste. 100, Louisville, KY 40202 (e-mail: arthur.malkani@louisville.edu).

J Knee Surg

Abstract

Approximately 20% of the patients are dissatisfied with their total knee arthroplasty (TKA). Computer technology has been introduced for TKA to provide real time intraoperative information on limb alignment and exact flexion/extension gap measurements. The purpose of this study was to determine if patient satisfaction could be improved with the use of robotic-assisted (RA) technology following primary TKA. A total of 120 consecutive patients undergoing RA-TKA with real time intraoperative alignment and gap balancing information were compared with a prospective cohort of 103 consecutive patients undergoing TKA with manual jig-based instruments during the same time period. There were no differences between groups with age, gender, baseline Knee Society Score (KSS) knee and function scores, follow-up, and ASA scores. TKAs were performed using same technique, implant design, anesthesia, and postoperative treatment protocols. Patient satisfaction survey using KSS and Likert scoring system were obtained at 1-year follow-up. Likert scoring system demonstrated 94% of the patients in the RA group were either very satisfied or satisfied versus 82% in the manual instruments TKA group ($p = 0.005$). RA-TKA group had better average scores of all five satisfaction questions although not significant. RA-TKA group had a better average overall satisfaction score of 7.1 versus 6.6 in the manual instrument group, $p = 0.03$. KSS function scores were significantly better at 6 weeks and 1 year postoperatively ($p = 0.02$, 0.005), and KSS knee scores were significantly better at 1 year postoperatively ($p = 0.046$). There are multiple reasons for patient dissatisfaction following primary TKA. Using intraoperative computer technology with RA surgery for patients undergoing a primary TKA, a significant improvement in patient satisfaction was demonstrated compared with TKA using conventional manual jig-based instruments. RA surgery provides several advantages in TKA including real time information in millimeters to help obtain balanced gaps, accurate bone cuts, reduced soft tissue injury, and achieve the target alignment which may lead to improved patient satisfaction.

Keywords
- total knee arthroplasty
- robotic-assisted
- patient satisfaction
- outcomes

received
June 21, 2019
accepted after revision
September 18, 2019

DOI https://doi.org/10.1055/s-0039-1700837.
ISSN 1538-8506.

In 2012, the number of total knee arthroplasty (TKA) performed in the United States was over 700,000 and projected to increase to 3.5 million procedures performed by 2030.[1] Todays health care system continues to place emphasis on patient reported outcomes and satisfaction following TKA. It has been previously demonstrated that only 75% of the patients are either satisfied or very satisfied with their TKA at 1-year follow-up.[2] Even with contemporary design TKA implants, approximately one in five (19%) primary TKA patients were not satisfied with their outcome.[3] Conversely, in a 5-year follow-up study of 384 unicompartmental knee arthroplasty patients, 91% of the patients were either very satisfied or satisfied with their knee function.[4] There are several reasons for patient dissatisfaction following TKAs including component malalignment and instability.[5] Malalignment of greater than 3 degree has been identified in 32% of conventional TKAs and can lead to symptoms of pain and instability.[6] Instability due to flexion and extension gap mismatch is also one of the leading etiologies of failure of a primary TKA leading to revision surgery.[7,8]

The ability to achieve and confirm the desired overall alignment and accurate gap balancing of the flexion and extension gaps intraoperatively can be challenging with conventional jig-based manual instruments. Manual jig-based instruments have demonstrated variability and inaccuracy during primary TKA since the surgeon has to resort to using gap measurement blocks or laminar spreaders to determine the accuracy of the flexion and extension gaps. The use of computer robotic technology has been shown to be effective in many industries such as manufacturing and automotive. In 1985, the first surgical application of industrial robotic technology was described when an industrial robotic arm was modified to perform a stereotactic brain biopsy with 0.05-mm accuracy.[9] Since then robotic-assisted (RA) technology has been used successfully in neurologic, cardiac, gynecologic, urologic, and more recently orthopedic surgery.[10,11]

RA surgery for TKA (Mako, Stryker, Mahwah, NJ) provides surgeons the ability to develop a 3D preoperative plan to obtain the desired limb and component alignment along with soft tissue balancing with gap measurements in 1-mm increments. Bone cuts and implant placement in the coronal, sagittal, and axial planes can be accomplished to obtain precisely balanced gaps and desired overall alignment and component position. Real time intraoperative information is available to confirm the target alignment and desired gap measurements with the ability to make any necessary intraoperative corrections after trial implants to achieve the desired goal.

Studies have been published comparing early outcomes related to the use of computer technology and RA TKA and manual or conventional TKA.[12–14] RA-TKA has been associated with decreased pain and improved early functional recovery, and reduced time to hospital discharge compared with conventional jig-based TKA.[13] The purpose of this study was to determine if overall patient satisfaction can be improved with the use of RA technology versus conventional jig-based instruments in patients undergoing primary TKA.

Materials and Methods

A total of 228 patients undergoing primary TKA using RA-TKA with intraoperative computer technology (Mako, Stryker, Mahwah, NJ) or traditional jig-based TKA using manual instruments were studied. Inclusion criteria included patients undergoing primary TKA for osteoarthritis and a minimum of 1-year follow-up. The pattern of osteoarthritic disease and deformity (degree of varus/valgus) were similar between the groups. In the RA-TKA group, two patients were excluded due to a periprosthetic joint infection. In the manual TKA group, one patient was excluded due to a periprosthetic joint infection, one patient was excluded due to a periprosthetic tibia fracture with tibial tray loosening, and one patient was excluded due to an extensor mechanism rupture with open arthrotomy and contamination. Therefore, 223 patients available for review: 120 consecutive patients that underwent primary TKA using CT-based computer technology with RA surgery were compared with a prospective cohort of 103 consecutive patients that underwent primary TKA using conventional jig-based TKA with manual instruments. Patients were scheduled on a consecutive basis with manual jig-based instruments used on days when the technology-based RA system was not available. Average age in the RA-TKA cohort was 68 years range (40–86 years) versus 66 years (range 44–87 years) in the manual jig-based TKA cohort ($p = 0.09$). The computer technology RA-TKA group consisted of 40% males and 60% females versus 37% males and 63% females in the manual jig-based TKA group ($p = 0.68$). Average BMI in the computer technology TKA cohort was 31.2 kg/m^2 (range 18–47) versus 34.7 kg/m^2 (range 20–47) in the manual TKA cohort ($p < 0.01$). The average follow-up was 17 months in the RA-TKA group versus 19 months in the manual TKA group with a minimum of 1 year ($p = 0.09$).

Institutional review board approval was obtained prior to initiating the study. All procedures were performed by a single surgeon using the same implant design (Triathlon PS TKA, Stryker, Mahwah, NJ). All cases were performed during the same time period using the same anesthesia team, postoperative protocols, surgical approach, and implant. Majority of the patients in both groups underwent cementless TKA and there were 10 cemented cases in the RA group and 14 cemented in the manual jig-based group due to osteoporotic bone. All patients received the same preoperative total joint education along with the same anesthesia and postoperative physical therapy and venous thromboembolism prophylaxis protocols with immediate weightbearing on the day of surgery. Patients were seen at 2 weeks, 6 weeks, and at 1 year postoperatively for clinical and radiographic evaluation.

RA-TKA Operative Technique

Preoperative CT scans were utilized to prepare a virtual 3D preoperative plan with respect to the desired component position, limb alignment, and gap measurements. The goal was to obtain equal gap measurements within 1 mm between the flexion and extension gaps and the medial and lateral gaps. The goal of the limb alignment was a target within 3 degrees of the mechanical axis and use the bone cuts to balance gaps instead of soft tissue releases unless the target fell out of

3 degrees window at which point a combination of bone cuts and soft tissue releases was utilized to achieve balanced gaps within 1 mm. Pins were placed intraincisional on the femoral side and extra-articular below the tibial tubercle in the tibial side for the tracking device. The hip center along with the medial and lateral malleolus was registered followed by mapping of the distal and proximal tibia. The patients' baseline limb alignment and gap measurements were recorded followed by adjusting the virtual preoperative plan through alterations in the femoral and tibial cuts in all planes prior to the actual cuts to achieve the desired target alignment and accurately balanced gaps within 1 mm.

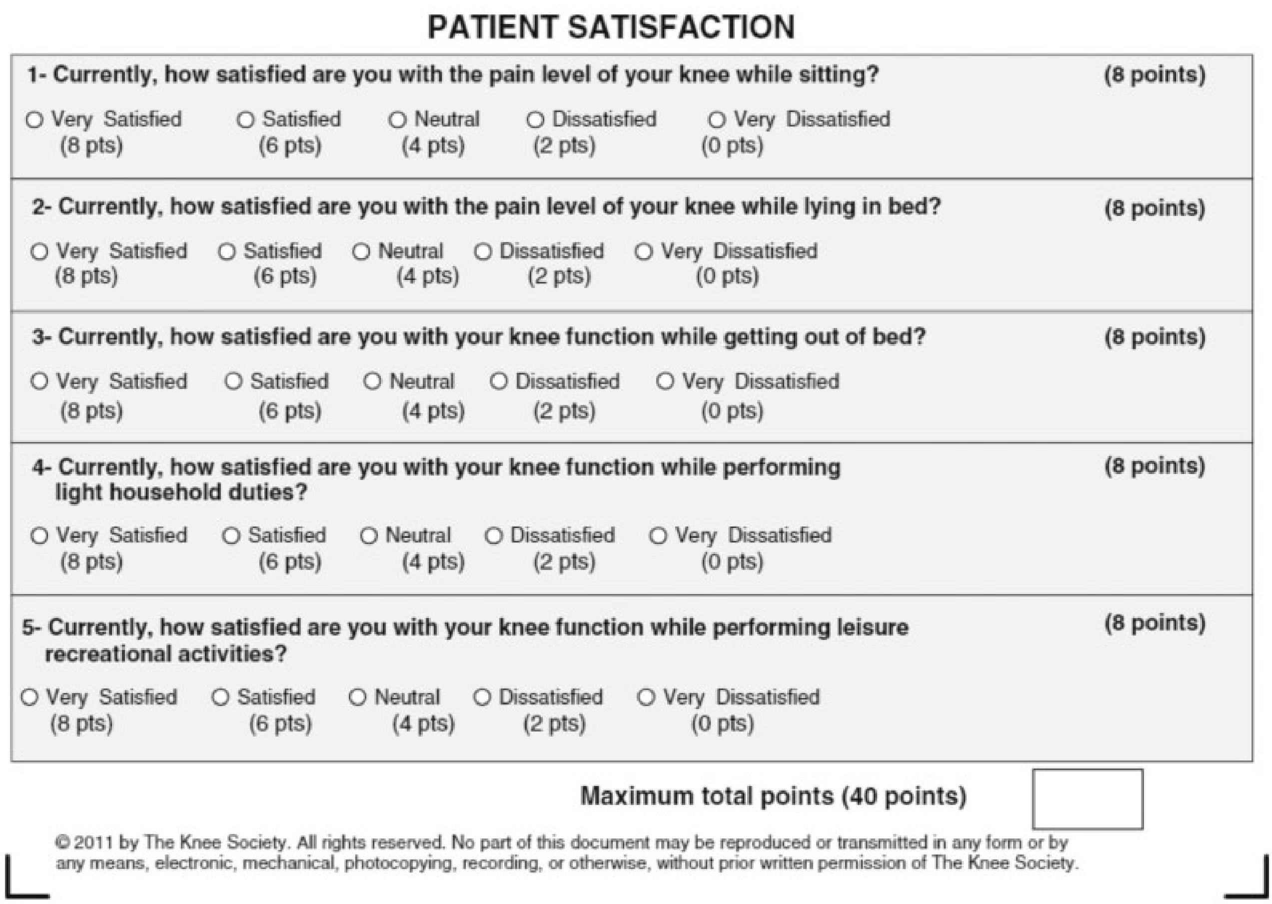
The distal femoral and proximal tibial cuts were completed with the RA arm and the extension gap balanced to within 1 mm between the medial and lateral gaps confirmed with the intraoperative computer technology tool on a screen. A tensioning device was placed in flexion after the PCL was resected and virtual adjustments were made using the intraoperative computer technology software tool to the femoral component in the axial and sagittal planes to balance the gaps followed by the completion of the femoral cuts using the RA arm to match the extension gap within 1 mm. Trial implants were used to confirm component position, limb alignment, and gap measurements followed by implant insertion. The patella was resurfaced in all patients using a standard free hand saw technique.

Manual Jig-Based TKA Operative Details

A measured resection technique was performed using intramedullary alignment for the distal femoral cut and an external alignment guide for the proximal tibial cut. Following sequential bone cuts on the distal femur and the proximal tibia, the extension gap was evaluated by using a rectangular gap block checker with calibrations. The remainder of the femoral cuts were completed to match the extension gap with the femoral rotation set to have a rectangular flexion gap. Adjustments were made to obtain balanced gaps using the calibrations on the gap block checker or using laminar spreaders and performing soft tissue releases or additional bone cuts when indicated. There were no technologic tools used in these cases to provide an objective number except for the flexion and extension blocks, laminar spreaders, and clinical judgment on soft tissue tension. The patella was resurfaced in all patients using a standard free hand saw technique. Trial components were inserted to manually check limb alignment, gap stability, and patella tracking. The same posterior stabilized implant utilized in the RA surgery was inserted in the jig-based manual instrument technique as well.

Data Collected

Patients were given the 2011 KSS system to complete independently at 1-year follow-up appointments.[15] In addition to the five questions in the patient satisfaction section of the KSS (displayed in ►**Fig. 1**), patients were asked to rate their



PATIENT SATISFACTION

1- Currently, how satisfied are you with the pain level of your knee while sitting? (8 points)

○ Very Satisfied (8 pts) ○ Satisfied (6 pts) ○ Neutral (4 pts) ○ Dissatisfied (2 pts) ○ Very Dissatisfied (0 pts)

2- Currently, how satisfied are you with the pain level of your knee while lying in bed? (8 points)

○ Very Satisfied (8 pts) ○ Satisfied (6 pts) ○ Neutral (4 pts) ○ Dissatisfied (2 pts) ○ Very Dissatisfied (0 pts)

3- Currently, how satisfied are you with your knee function while getting out of bed? (8 points)

○ Very Satisfied (8 pts) ○ Satisfied (6 pts) ○ Neutral (4 pts) ○ Dissatisfied (2 pts) ○ Very Dissatisfied (0 pts)

4- Currently, how satisfied are you with your knee function while performing light household duties? (8 points)

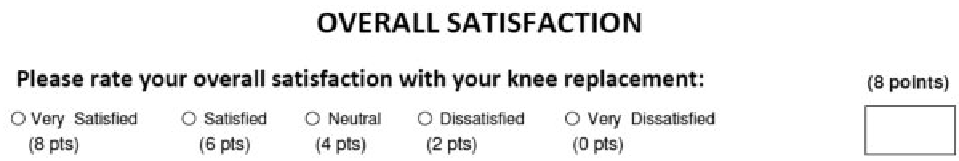
○ Very Satisfied (8 pts) ○ Satisfied (6 pts) ○ Neutral (4 pts) ○ Dissatisfied (2 pts) ○ Very Dissatisfied (0 pts)

5- Currently, how satisfied are you with your knee function while performing leisure recreational activities? (8 points)

○ Very Satisfied (8 pts) ○ Satisfied (6 pts) ○ Neutral (4 pts) ○ Dissatisfied (2 pts) ○ Very Dissatisfied (0 pts)

Maximum total points (40 points)

Fig. 1 The patient satisfaction portion of the 2011 Knee Society Scoring System.


OVERALL SATISFACTION

Please rate your overall satisfaction with your knee replacement: (8 points)

○ Very Satisfied (8 pts) ○ Satisfied (6 pts) ○ Neutral (4 pts) ○ Dissatisfied (2 pts) ○ Very Dissatisfied (0 pts)

Fig. 2 Overall satisfaction at 1-year postoperative total knee arthroplasty, using a 5-point Likert scale of possible responses.

overall satisfaction of their knee replacement on a similar 5-point Likert scale; the additional question asked was "Currently, how satisfied are you overall with your knee?" with very satisfied, satisfied, neutral, dissatisfied, and very dissatisfied as possible responses (►**Fig. 2**). The 5-point Likert scale has been well-established, and the format includes responses in a range to capture the patients feeling for a specific question.[16] The original version of the Knee Society Score (KSS function and knee scores) was also recorded preoperatively and at 6-week and 1-year follow-up visits. Patient reported outcome data were recorded by a third party independent of the surgical team. Clinical results and complications were also assessed and compared between the groups; length of stay (LOS), operative time, and pre and postoperative active range of motion were analyzed. Data were prospectively collected and recorded in a Microsoft Excel Spreadsheet (2017 Microsoft Office Professional Plus, Redmond, WA). When comparing outcomes and demographic data of the two cohorts, continuous variables were analyzed using a two-tailed *t*-test. Categorical data compared between the two cohorts were analyzed using a chi-squared test unless data frequency was small enough to preclude the use of the test; in this case a Fisher's exact test was used. Statistical significance was set as a *p*-value of <0.05 for all analyses. All statistical analyses were performed using SPSS version 25 (International Business Machine Corporation, Armonk, NY).

Results

Overall patient reported satisfaction reported with a Likert scoring system demonstrated a statistically significant difference with 94% of the patients in the RA-TKA group being either very satisfied or satisfied versus 82% in the jig-based TKA group ($p = 0.036$). ►**Table 1** shows the results of the overall satisfaction question. The second question of the KSS which assesses satisfaction with the level of pain while at rest showed greater number of satisfied or very satisfied patient in the RA group compared with the manual jig-based group, 86 versus 77%, but this did not reach significance. A higher percentage of patients in the RA-TKA group responded as being either satisfied or very satisfied to each of the five satisfaction questions. A summary of the results of the five questions of KSS patient satisfaction section is shown in ►**Table 2**. Analysis was also performed considering the average numerical response to each question with the results demonstrated in ►**Table 3**. When comparing the mean response of patient data, the overall satisfaction question again demonstrated statistical significance ($p = 0.027$) with the average response value out of 8 possible points being 7.1 and 6.6 in the RA-TKA and manual TKA groups, respectively. The RA-TKA group had a better average total score on the KSS satisfaction survey and better average score for each of the five satisfaction questions although this did not reach statistical significance.

Both groups had improved Knee Society Scores following surgery, and the preoperative KSS function and knee scores were not different between the two groups ($p = 0.73$, $p = 0.17$). The RA group showed improved postoperative function scores compared with the manual jig-based instruments group which was statistically significant at both 6 weeks and 1 year. KSS function score in the RA group had a 6-week and 1-year average score of 63 and 80 versus 58 and 73 in the manual group ($p = 0.02$, $p = 0.005$). The RA-TKA

Table 1 Results of the overall satisfaction question between the robotic-assisted TKA group and the manual instruments TKA group

Overall satisfaction question	RA-TKA	Manual TKA	*p*-Value
Very satisfied or satisfied	113-94%	84-82%	0.036
Neutral	5-4%	13-13%	ns
Dissatisfied or very dissatisfied	2-2%	6-6%	ns

Abbreviations: ns, non-significant; RA, robotic-assisted; TKA, total knee arthroplasty.

Table 2 A summary of the results of the five questions of KSS patient satisfaction section between the computer technology TKA group and the manual instruments TKA group

		VD/D	N	S/VS	*p*-Value
Question 1	RA-TKA Manual TKA	5-4% 3-3%	9-8% 11-11%	106-88% 89-86%	0.83
Question 2	RA-TKA Manual TKA	7-6% 8-8%	10-8% 16-16%	103-86% 79-77%	0.23
Question 3	RA-TKA Manual TKA	6-5% 7-7%	10-8% 16-16%	104-87% 80-78%	0.34
Question 4	RA-TKA Manual TKA	6-5% 5-5%	12-10% 20-19%	102-85% 78-76%	0.20
Question 5	RA-TKA Manual TKA	10-8% 11-11%	18-15% 17-17%	92-77% 75-73%	0.60

Abbreviations: N, neutral; RA, robotic-assisted; S/VS, satisfied/very satisfied; TKA, total knee arthroplasty; VD/D, very dissatisfied/dissatisfied.

Table 3 Comparison of average numerical responses to each of the five questions in KSS patient satisfaction section, the total section score, and the overall Likert question between the computer technology TKA group and the manual instruments TKA group

	RA-TKA	Manual TKA	Δ	*p*-Value
Question 1	7.1	7.0	0.07	0.74
Question 2	6.8	6.4	0.43	0.09
Question 3	6.8	6.5	0.30	0.22
Question 4	6.7	6.3	0.39	0.10
Question 5	6.2	5.9	0.30	0.28
Total score	33.6	32.0	1.54	0.16
Overall satisfaction question	7.1	6.6	0.48	0.027

Abbreviations: KSS, Knee Society Score; RA, robotic-assisted; TKA, total knee arthroplasty.

Table 4 Preoperative, 6 week and 1-year postoperative Knee Society Scores and length of stay (LOS) and operative time compared between the robotic-assisted TKA group and the manual TKA group

	RA-TKA	Manual TKA	*p*-Value
Operative time (h, min)	1:36	1:26	<0.01
LOS (d)	2.1	2.6	0.0004
Preoperative KSS function score	44	43	0.73
6-week KSS function score	63	58	0.02
1-year KSS function score	80	73	0.005
Preoperative KSS knee score	41	39	0.17
6-week KSS knee score	80	77	0.11
1-year KSS knee score	85	82	0.046

Abbreviations: KSS, Knee Society Score; TKA, total knee arthroplasty.

group also had a significantly better average 1-year postoperative KSS knee score of 85 versus 82 in the manual group ($p = 0.046$). A summary of the KSS knee and function scores, LOS and operative time is seen in ►**Table 4**.

Active knee range of motion was the same preoperatively with an average of 2 to 110 degrees and 2 to 108 degrees in the RA-TKA and manual TKA groups, respectively ($p = 0.38$ and $p = 0.16$ for extension and flexion). Postoperative active knee range of motion on average was 0 to 119 degrees and 1 to 116 degrees in the RA-TKA and manual TKA groups, respectively ($p = 0.88$ and $p = 0.02$ for extension and flexion). Average total operative time was higher in the RA-TKA group at 1 hour 36 minutes versus 1 hour 26 minutes in the manual TKA group ($p < 0.01$). Average LOS was 2 days in the RA-TKA group versus 3 days in the manual jig-based TKA group using the same postoperative and discharge protocols ($p = 0.0004$). Both groups had similar postoperative complications. There were nine manipulations under anesthesia in both groups. If patients did not reach active range of motion to 105 degrees of flexion at 6 weeks then manipulation was recommended. Arthroscopic lysis of adhesions was performed in six patients in the RA-TKA group and in three patients in the manual TKA group. There were two cases of nonfatal pulmonary embolism in the RA group (►**Table 5**).

Table 5 Postoperative complications of the robotic-assisted TKA and manual instruments TKA groups

Postoperative complications	RA-TKA	Manual TKA
No. of postoperative revision TKAs	0	0
Contracture requiring MUA	9	9
Arthroscopic lysis of adhesions	6	3
Hematoma	0	1
Nonfatal PE	2	0

Abbreviations: MUA, manipulation under anesthesia; PE, pulmonary embolism; RA, robotic-assisted; TKA, total knee arthroplasty.

Discussion

At present, approximately 19% of the patients are dissatisfied following primary TKA.[3] Patient satisfaction is affected by a multitude of variables many of which are subjective.[3,5] Many studies have shown that accuracy of ligament balancing, flexion and extension gaps, and alignment is essential for function and endurance of the prosthetic knee.[7,8,17–19] Despite achieving the desired alignment in TKA, patients can still be dissatisfied due to multiple reasons such as instability, contracture, chronic pain, the inability to return to an active lifestyle, and the failure to meet expectations. Instability is a significant mode of failure following primary TKA and leads to patient dissatisfaction.[5,7,8] Gustke et al observed the effect of soft tissue balancing achieved through intraoperative use of a sensor that replaces tibial insert trials and detects forces across the medial and lateral tibiofemoral interfaces as the knee taken through full range-of-motion (ROM).[20] The use of this sensor technology provides objective intraoperative information on gap measurements with greater accuracy compared with manual instruments with an actual number which the surgeon can use to make corrections and confirm balanced gaps. They found that optimal balancing using this intraoperative sensor technology correlates with higher patient satisfaction. They showed that 1 or 2 mm of gap imbalance can lead to significantly increased pressures in the medial or lateral compartments. However, to adjust the increased loads using sensors requires soft tissue releases or recuts, which can be challenging using manual jig-based instruments. In another study, Gustke et al report improved short-term (6 months) outcomes with sensor-aided soft tissue balancing when comparing KSS and Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores.[21]

Use of advanced technology in TKA to help achieve the desired surgical goals of target alignment and balanced gaps has demonstrated improved outcomes and can benefit the surgeon intraoperatively to achieve these goals with greater accuracy than manual instruments. A meta-analysis of level I randomized trials comparing TKA performed with computer navigation to those performed with conventional instruments found that computer navigation leads to more accurate mechanical alignment and higher increases in KSS at 3 month and 12 to 32 month-follow-up; however, navigation alone does not provide accurate soft tissue gap information.[22] The use of RA surgery with associated preoperative planning has demonstrated improved gap balancing and alignment that has previously not been achieved by traditional methods.[12] Mannan et al presented a systematic review and meta-analysis of five studies including 181 RA-TKAs and 159 conventional TKAs with the RA group having a better incidence or improved accuracy of ideal mechanical alignment that was statistically significant when comparing the groups.[23]

Liow et al present a prospective randomized trial of 31 RA-TKA cases and 29 manual TKA cases and found that the conventional group had a rate of mechanical axis deviation of greater than 3 degree and notching at 19.4% and 10.3% versus 0% for both in the RA-TKA group. Further, joint-line restoration was better in the RA-TKA group with only 3.23% being joint-line outliers of >5 mm versus 20.6% in the conventional group.[24] The group found that RA-TKA patients had better SF-36 vitality ($p = 0.03$) and emotional roles ($p = 0.02$), as well as a larger number of patients achieving the SF-36 vitality minimum clinically important difference (48 vs. 14%, $p = 0.009$).[25] In another study looking at 6-month outcomes comparing 20 RA-TKA and 20 conventional TKA patients, improved WOMAC scores were found in the RA-TKA cohort with higher function and decreased pain.[14] They extrapolated the sum of patient pain and physical function scores to come up with a total satisfaction score and concluded that the RA-TKA group had statistically significant better short-term outcomes. Kayani et al demonstrate improved postoperative results with RA-TKA patients; in their prospective cohort study, 40 consecutive RA-TKA patients are compared with 40 consecutive conventional TKA patients. They found statistically significant reduced postoperative pain, decreased analgesia requirement, decreased reduction in postoperative hemoglobin, decreased time to straight leg raise and increased maximum knee flexion at discharge, reduced number of physiotherapy sessions, and shorter LOS in the RA-TKA group.[13]

These presented studies demonstrate a paradigm that RA surgery for TKA has advantages including improved mechanical alignment, gap balancing, outcome measures, and patient reported outcomes. Further, RA surgery differs from manual TKA in defined ways. Haptic boundaries of the saw blade are created from CT data and limit soft tissue damage and the use of the robotic technology and image guidance promotes accurate bone cuts and decreased soft tissue release. The use of manual jig-based instruments does not provide real time information on femoral component alignment in the coronal, axial, and sagittal planes nor does it provide tibial component position with the same degree of accuracy compared with the use of intraoperative computer technology. Both measured resection techniques and gap balancing techniques for performing primary TKA do not provide the exact numerical information on component alignment or the exact gap measurement. This study demonstrated improved patient satisfaction up to 94% in the RA-TKA group compared with 82% in the manual jig-based group (►**Fig. 3**). RA surgery with real time information on implant position and gap measurements with 1-mm increments allows the surgeon to accurately place the implants with greater precision (►**Fig. 4**). We feel that a combination of the several advantages of RA-TKA surgery including improved preoperative planning, more accurate bone cuts, precise gap balancing, decreased soft tissue trauma and the ability to achieve and confirm the target alignment has likely contributed to the increased patient satisfaction.

Improved patient satisfaction with RA unicompartmental arthroplasty has been demonstrated by Pearle et al. They prospectively analyzed satisfaction and survivorship in patients undergoing robotic-assisted unicompartmental

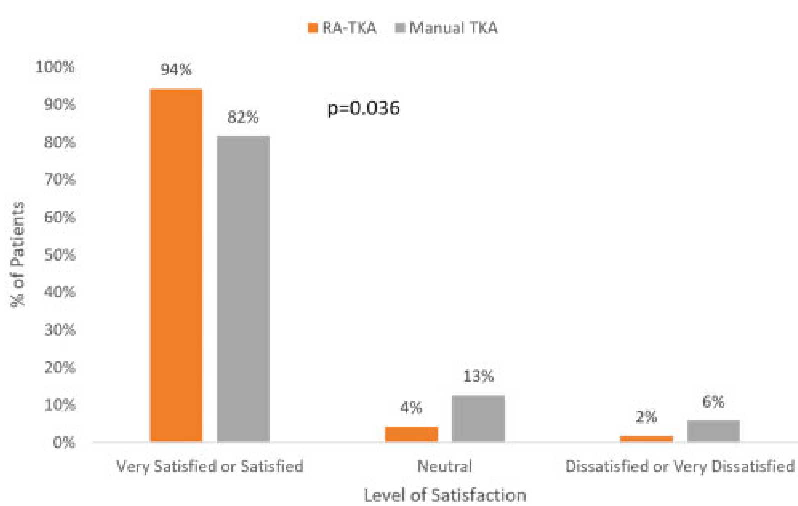


Fig. 3 Bar graph demonstrating the distribution of patient satisfaction 1 year postoperatively between the robotic assisted with intraoperative computer technology total knee arthroplasty (TKA) group and the manual instruments TKA group based on the overall satisfaction question.

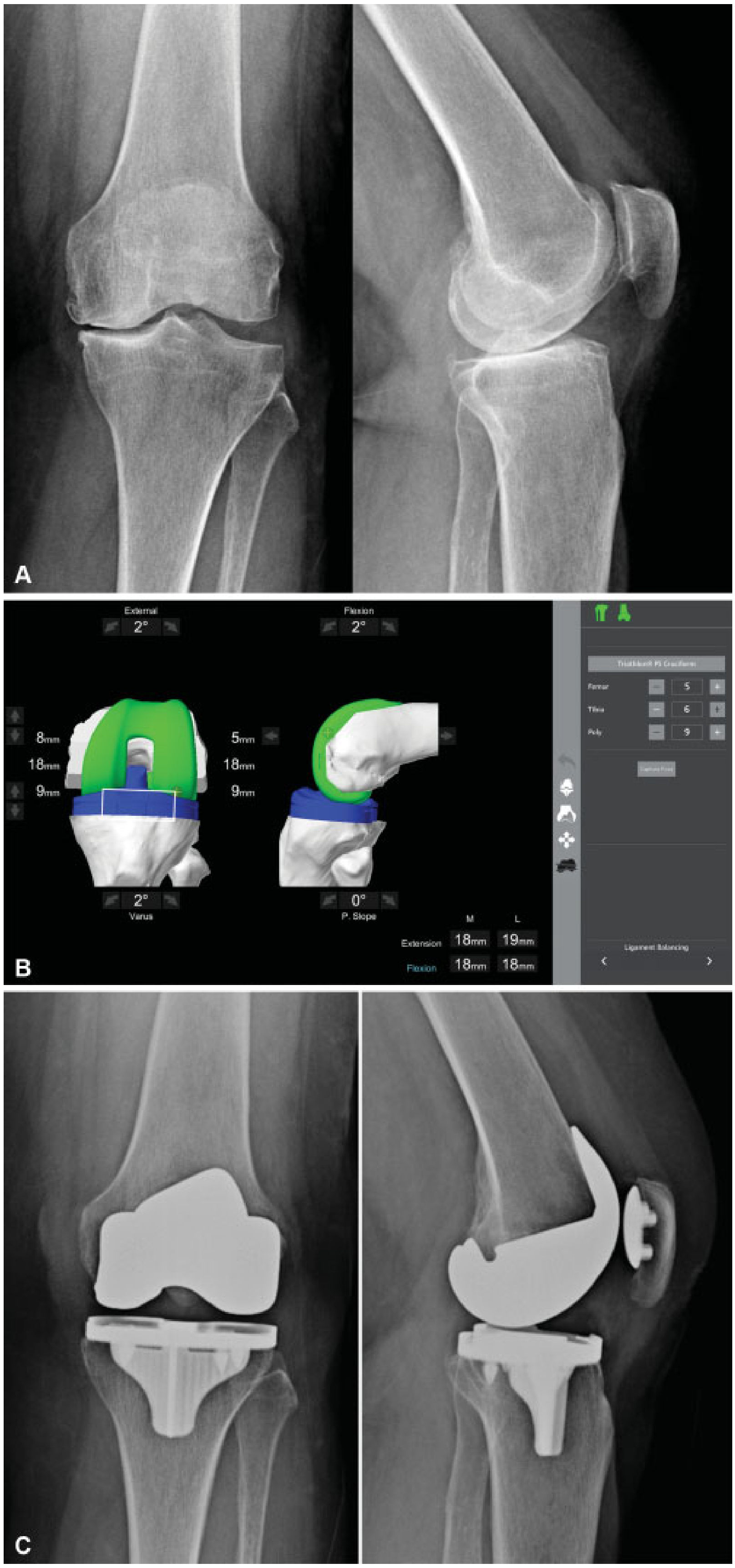


Fig. 4 (**A**) Preoperative AP and lateral radiographs of a 73-year-old female with left knee OA undergoing robotic assisted with intraoperative computer technology total knee arthroplasty (TKA). (**B**) Final intraoperative medial and lateral flexion and extension gap measurements within 1 mm with components in place. (**C**) Postoperative AP and lateral radiographs following robotic assisted with intraoperative computer technology TKA. AP, anteroposterior; OA, osteoarthritis.

knee arthroplasty (RA-UKA) by six surgeons at separate institutions with an average follow-up of 29.6 months.[26] The study group included 797 patients (909 knees), and at 2.5-year follow-up there was a 98.8% survivorship (11 knees reported as revised), and a worst-case survivorship of 96.0% when including the 35 patients declining participation in the study. Of the patients that did not undergo revision, 92% were very satisfied or satisfied, 4% were neutral, and 4% were dissatisfied or very dissatisfied. Kleeblad et al present a prospective, multicenter study assessing survivorship and patient satisfaction of RA-UKA at 5-year postoperative follow-up in 384 patients (432 knees).[4] They found a 97% survivorship (13 revisions), and in patients that did not undergo revision 91% were very satisfied or satisfied, 5% were neutral, and 4% were dissatisfied or very dissatisfied. These studies further corroborate RA surgery in the knee that leads to better patient satisfaction.

As previous studies comparing results of RA-TKA to conventional jig-based TKA have shown improved immediate and short-term results, the results of this study demonstrate improved outcomes with respect to patient satisfaction in the RA-TKA group at minimum 1-year follow-up. When comparing the numeric mean response to each question as well as the overall satisfaction question, RA-TKA patients consistently had higher rates of satisfaction with each of the five questions, the total score of the patient satisfaction section, and the overall satisfaction question, with statistical significance reached with the overall satisfaction question (►**Table 3**). When analyzing the data categorically, the RA-TKA cohort had a higher percentage of patients selecting that they were satisfied or very satisfied with each of the five questions and the overall Likert satisfaction question (►**Table 2**). Although statistical significance was not achieved in each question, there is a consistent trend with each question in both modes of analysis showing RA-TKA patients to be more satisfied. The overall Likert satisfaction question showed a statistically significant difference with greater satisfaction in the RA group.

With respect to the KSS knee and function scores, the RA group showed statistically significant better postoperative KSS function scores with a 6-week and 1-year average score of 63 and 80 versus 58 and 73 in the manual group ($p = 0.02$, $p = 0.005$). The RA-TKA group also had a better average 6-week postoperative KSS knee score of 80 versus 77 in the manual group ($p = 0.11$) and a significantly better average 1-year postoperative KSS knee score of 85 versus 82 in the manual group ($p = 0.046$). We feel that the ability to more accurately balance the flexion and extension gaps using computer technology as compared with blocks or laminar spreaders using manual jig-based instruments in all likelihood leads to a more stable knee and therefore improved patient satisfaction. The amount of flexion gap that potentially opens with posterior cruciate bone block resection can be variable and clinically this may create a flexion-extension mismatch which cannot be detected intraoperatively using clinical acumen or blocks or laminar spreaders leading to instability and patient discomfort with stair climbing and recreation activities. However, using computer technology, gaps can be detected within 1 mm allowing intraoperative adjustments to be made to resolve any flexion-extension gap mismatch. These results show a similar trend with previously presented studies and particularly consistent with the RA-UKA data, suggesting that RA surgery leads to improved patient satisfaction, likely due to a combination of the previously presented advantages of RA technology and associated ability to obtain real time intraoperative information on implant alignment and gap measurements in TKA.

There are several limitations to this study. This was not a randomized or blinded trial but our initial learning experience using RA surgery which also accounted for the longer surgical time in the RA group. However, the two cohorts did not differ with respect to patient demographics and baseline KSS knee and function scores. All patients went through the same preoperative education, and all procedures were performed at the same institution with the same surgical technique using the same implant design and the same postoperative pain management and physical therapy protocols. The study was further limited with the relatively short-term follow-up of 1 year, and the focus of the study is on patient reported outcomes and not radiographic or biomechanical data comparisons. There were no cases of aseptic loosening or instability leading to revision in either group at 1-year follow-up. We chose the KSS questionnaire as a comparative tool because it serves as a good measurement tool for subjective variables and latent traits.[27] The Likert scale system is one of the most popular instruments to measure such latent traits for research purposes.[16] We felt that adding a simple question of "how satisfied are you overall with your knee?" is an excellent way to gauge outcomes.

The use of RA surgery is becoming more widespread in all surgical fields. With the use of intraoperative computer technology and RA-TKA, we were able to demonstrate 94% either satisfied or very satisfied patients undergoing RA-TKA compared with 82% with conventional TKA using manual jig-based instruments, which is a positive change compared with aforementioned studies in the literature with the use of manual instruments.[2,3] RA surgery provides several advantages to patients undergoing TKA including real time intraoperative numerical information on implant alignment and gap measurements, more accurate bone cuts, reduced soft tissue injury, and less soft tissue release due to gap balancing using primarily bone cuts. These advantages with current technologic innovation using RA surgery in TKA can lead to improved gap balancing and implant placement and help avoid instability and pain leading to the improved patient satisfaction. Further work in addition to a prospective randomized study and longer follow-up will help determine the efficacy of this technology for use in primary TKA.

Conflict of Interest
A.M. reports personal fees and nonfinancial support from Stryker, outside the submitted work. All the other authors report no conflict of interest.

References

1 Kurtz SM, Lau E, Ong K, Zhao K, Kelly M, Bozic KJ. Future young patient demand for primary and revision joint replacement: national projections from 2010 to 2030. Clin Orthop Relat Res 2009;467(10):2606–2612

2 Noble PC, Conditt MA, Cook KF, Mathis KB. The John Insall award: patient expectations affect satisfaction with total knee arthroplasty. Clin Orthop Relat Res 2006;452(452):35–43

3 Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KDJJ. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res 2010;468(01):57–63

4 Kleeblad LJ, Borus TA, Coon TM, Dounchis J, Nguyen JT, Pearle AD. Midterm survivorship and patient satisfaction of robotic-arm-assisted medial unicompartmental knee arthroplasty: a multicenter study. J Arthroplasty 2018;33(06):1719–1726

5 Gunaratne R, Pratt DN, Banda J, Fick DP, Khan RJK, Robertson BW. Patient dissatisfaction following total knee arthroplasty: a systematic review of the literature. J Arthroplasty 2017;32(12):3854–3860

6 Mason JB, Fehring TK, Estok R, Banel D, Fahrbach K. Meta-analysis of alignment outcomes in computer-assisted total knee arthroplasty surgery. J Arthroplasty 2007;22(08):1097–1106

7 Sharkey PF, Hozack WJ, Rothman RH, Shastri S, Jacoby SM. Insall Award paper. Why are total knee arthroplasties failing today? Clin Orthop Relat Res 2002;(404):7–13

8 Fehring TK, Valadie AL. Knee instability after total knee arthroplasty. Clin Orthop Relat Res 1994;(299):157–162

9 Hockstein NG, Gourin CG, Faust RA, Terris DJ. A history of robots: from science fiction to surgical robotics. J Robot Surg 2007;1(02):113–118

10 Zelhart M, Kaiser AM. Robotic versus laparoscopic versus open colorectal surgery: towards defining criteria to the right choice. Surg Endosc 2018;32(01):24–38

11 Matthews CA. New developments in robotics and single-site gynecologic surgery. Clin Obstet Gynecol 2017;60(02):296–311

12 Song E-K, Seon J-K, Yim J-H, Netravali NA, Bargar WL. Robotic-assisted TKA reduces postoperative alignment outliers and improves gap balance compared to conventional TKA. Clin Orthop Relat Res 2013;471(01):118–126

13 Kayani B, Konan S, Tahmassebi J, Pietrzak JRT, Haddad FS. 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 Joint J 2018;100-B(07):930–937

14 Marchand RC, Sodhi N, Khlopas A, et al. Patient satisfaction outcomes after robotic arm-assisted total knee arthroplasty: a short-term evaluation. J Knee Surg 2017;30(09):849–853

15 Noble PC, Scuderi GR, Brekke AC, et al. Development of a new Knee Society Scoring System. Clin Orthop Relat Res 2012;470(01):20–32

16 Likert R. A technique for the measurement of attitudes. Arch Psychol 1932;22:55

17 Kuriyama S, Ishikawa M, Nakamura S, Furu M, Ito H, Matsuda S. No condylar lift-off occurs because of excessive lateral soft tissue laxity in neutrally aligned total knee arthroplasty: a computer simulation study. Knee Surg Sports Traumatol Arthrosc 2016;24(08):2517–2524

18 Nakamura S, Ito H, Yoshitomi H, Kuriyama S, Komistek RD, Matsuda S. Analysis of the flexion gap on in vivo knee kinematics using fluoroscopy. J Arthroplasty 2015;30(07):1237–1242

19 Wasielewski RC, Galante JO, Leighty RM, Natarajan RN, Rosenberg AG. 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

20 Gustke KA, Golladay GJ, Roche MW, Jerry GJ, Elson LC, Anderson CR. Increased satisfaction after total knee replacement using sensor-guided technology. Bone Joint J 2014;96-B(10):1333–1338

21 Gustke KA, Golladay GJ, Roche MW, Elson LC, Anderson CR. A new method for defining balance: promising short-term clinical outcomes of sensor-guided TKA. J Arthroplasty 2014;29(05):955–960

22 Rebal BA, Babatunde OM, Lee JH, Geller JA, Patrick DA Jr, Macaulay W. Imageless computer navigation in total knee arthroplasty provides superior short term functional outcomes: a meta-analysis. J Arthroplasty 2014;29(05):938–944

23 Mannan A, Vun J, Lodge C, Eyre-Brook A, Jones S. Increased precision of coronal plane outcomes in robotic-assisted total knee arthroplasty: a systematic review and meta-analysis. Surgeon 2018;16(04):237–244

24 Liow MHL, Xia Z, Wong MK, Tay KJ, Yeo SJ, Chin PL. Robot-assisted total knee arthroplasty accurately restores the joint line and mechanical axis. A prospective randomised study. J Arthroplasty 2014;29(12):2373–2377

25 Liow MHL, Goh GS-HH, Wong MK, Chin PL, Tay DK-JJ, Yeo S-JJ. Robotic-assisted total knee arthroplasty may lead to improvement in quality-of-life measures: a 2-year follow-up of a prospective randomized trial. Knee Surg Sports Traumatol Arthrosc 2017;25(09):2942–2951

26 Pearle AD, van der List JP, Lee L, Coon TM, Borus TA, Roche MW. Survivorship and patient satisfaction of robotic-assisted medial unicompartmental knee arthroplasty at a minimum two-year follow-up. Knee 2017;24(02):419–428

27 Scuderi GR, Bourne RB, Noble PC, Benjamin JB, Lonner JH, Scott WN. The new Knee Society Knee Scoring System. Clin Orthop Relat Res 2012;470(01):3–19