Results of Robotic-Assisted Versus Manual Total Knee Arthroplasty at 2-Year Follow-up

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Abstract

Robotic-assisted technology has been developed to optimize the consistency and accuracy of bony cuts, implant placements, and knee alignments for total knee arthroplasty (TKA). With recently developed designs, there is a need for the reporting longer than initial patient outcomes. Therefore, the purpose of this study was to compare manual and robotic-assisted TKA at 2-year minimum for: (1) aseptic survivorship; (2) reduced Western Ontario and McMaster Universities Osteoarthritis Index (r-WOMAC) pain, physical function, and total scores; (3) surgical and medical complications; and (4) radiographic assessments for progressive radiolucencies. We compared 80 consecutive cementless robotic-assisted to 80 consecutive cementless manual TKAs. Patient preoperative r-WOMAC and demographics (e.g., age, sex, and body mass index) were not found to be statistically different. Surgical data and medical records were reviewed for aseptic survivorship, medical, and surgical complications. Patients were administered an r-WOMAC survey preoperatively and at 2-year postoperatively. Mean r-WOMAC pain, physical function, and total scores were tabulated and compared using Student's *t*-tests. Radiographs were reviewed serially throughout patient's postoperative follow-up. A $p < 0.05$ was considered significant. The aseptic failure rates were 1.25 and 5.0% for the robotic-assisted and manual cohorts, respectively. Patients in the robotic-assisted cohort had significantly improved 2-year postoperative r-WOMAC mean pain (1 ± 2 vs. 2 ± 3 points, $p = 0.02$), mean physical function (2 ± 3 vs. 4 ± 5 points, $p = 0.009$), and mean total scores (4 ± 5 vs, 6 ± 7 points, $p = 0.009$) compared with the manual TKA. Surgical and medical complications were similar in the two cohorts. Only one patient in the manual cohort had progressive radiolucencies on radiographic assessment. Robotic-assisted TKA patients demonstrated improved 2-year postoperative outcomes when compared with manual patients. Further studies could include multiple surgeons and centers to increase the generalizability of these results. The results of this study indicate that patients who undergo robotic-assisted TKA may have improved 2-year postoperative outcomes.

Keywords
- robotic-assisted TKA
- manual TKA
- WOMAC

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Despite excellent survivorship, many patients are dissatisfied with total knee arthroplasties (TKAs)[1–4] Multiple factors may contribute to this, including improper implant placement, alignment, balancing, or rotation.[5–8] To help address some of these concerns, robotic-assisted TKA technology was developed. Numerous studies have shown that this technology may help attain improved implant placement more accurately and consistently than manual techniques.[9–12] Additionally, robotic-assisted TKA may show increased early function and pain scores and less soft tissue damage, compared with conventional techniques.[13–16]

These potential benefits in implant placement and precision would hopefully translate to improved patient outcomes and implant survivorship with the use of modern haptically performed robotic systems. However, the technology is relatively new and therefore there are few publications that investigate longer term follow-up.[17] Marchand et al[18,19] demonstrated that patients who underwent robotic-assisted TKA showed significantly improved Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores when compared with manual TKA after 6-month (7 ± 8 vs. 14 ± 8 points, $p < 0.05$) and 1-year (6 ± 6 vs. 9 ± 8 points, $p = 0.03$) follow-ups. While it could be inferred that patients will continue to have improved outcomes with time, there is limited 2-year data on haptically performed robotic-assisted TKA.

As previously mentioned, patients who underwent robotic-assisted TKA have shown improvements up to 1-year postoperative assessments when compared with manual techniques.[19] Current literature is limited to 2-year patient-reported outcome measures.[17] Therefore, the purpose of this study was to compare manual and robotic-assisted TKA at 2-year minimum follow-up for (1) aseptic survivorship; (2) reduced WOMAC (r-WOMAC) pain, physical function, and total scores; (3) surgical and medical complications; and (4) radiographic assessments for progressive radiolucencies.

Methods

Patients who had symptomatic knee osteoarthritis undergoing primary TKA by a single-board certified surgeon operating at a high-volume nonacademic hospital from April 1, 2015, to June 1, 2016, and from April 1, 2017, to December 31, 2017, were included in this study. These included 80 consecutive manual and 80 consecutive robotic-assisted TKAs. The manual cohort consisted of the last cases performed by the surgeon after 30 years of experience. The robotic-assisted cohort was comprised of patients who underwent robotic-assisted TKA after the surgeon had 6 months of experience. This cohort was chosen because during the first 6 months of robotic-assisted use, the surgeon used cemented implants. To reduce potential confounders, a cohort of cementless robotic-assisted TKA cases were chosen. The inclusion criteria for this study included the following: patients who had knee osteoarthritis undergoing primary uncemented TKA with either conventional or robotic-assisted techniques and had completed their 2-year r-WOMAC survey. The r-WOMAC survey is a self-administered evaluation of pain and physical function that has been validated as a reliable and comparable version of the WOMAC survey and can be administered in person or electronically.[20–22] The survey consists of 12 items that are categorized into pain (five items) and physical function (seven items). Each item is answered from none (0) to extreme (4) with mild (1), moderate (2), and severe (3) choices. Total scores are the sum of the pain and physical function scores. Patients were excluded if they underwent bilateral TKA, conversion of a unicompartmental knee arthroplasty to a primary, revision arthroplasty, and had retained hardware or underwent hardware removal at the time of surgery. This study had institutional review board approval.

The two cohorts were found to have no statistically significant differences in preoperative mean r-WOMAC total, physical functional, and pain scores (►**Table 1**). In addition, no significant differences were found in patient demographics (age, sex, body mass index [BMI], or limb laterality) between the study and matched cohorts (►**Table 2**).

All patients received a spinal block and an ultrasound-guided adductor canal block in addition to titrated sedation intraoperatively. A pneumatic tourniquet was utilized and elevated to 300 mm Hg before a medial parapatellar arthrotomy approach was used. The patella was resurfaced and sized first in both groups. In the manual group, a flexible intramedullary guide rod was placed in the femur and the distal femoral extension cut was set to 5 degrees of valgus. The distal femoral cutting block was then placed in approximately 3 degrees of external rotation in reference to the transepicondylar axis. The posterior femoral condyles, anterior femur, and chamfer cuts were made sequentially. An extramedullary tibial cutting jig was utilized and an approximately 9-mm high side proximal tibia resection was made. Medial and lateral flexion and extension gaps were subjectively assessed using trial components.

Table 1 Preoperative r-WOMAC scores

Preoperative r-WOMAC	Manual TKA		Robotic-assisted TKA		*p*-Value
	Mean ± SD	Range	Mean ± SD	Range	
Pain	10 ± 3	2–20	9 ± 3	2–20	0.21
Physical function	13 ± 4	1–26	13 ± 5	2–28	0.37
Total	23 ± 7	6–46	23 ± 8	4–28	0.29

Abbreviations: r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; SD, standard deviation; TKA, total knee arthroplasty.
Note: *p*-Values calculated using independent samples *t*-test.

Table 2 Patient characteristics of study cohorts

	Manual TKA ($n = 80$)	Robotic-assisted TKA ($n = 80$)	p-Value
Age	65 ± 8 (46–81)	67 ± 8 (46–84)	0.17[a]
BMI (kg/m^2)	32 ± 8	31 ± 7	0.22[a]
Sex			
Male (%)	46 (58)	51 (64)	0.42[b]
Female (%)	34 (42)	29 (36)	
Laterality			
Right (%)	42 (53)	49 (60)	0.26[b]
Left (%)	38 (47)	31 (40)	

Abbreviations: BMI, body mass index; TKA, total knee arthroplasty.
Note: Statistics shown as mean ± standard deviation (range) or (column percentage).
[a]Independent sample's *t*-test.
[b]Pearson's Chi-square test.

The robotic-assisted TKA patients underwent a preoperative computed tomography (CT) scan and the images were uploaded to the robotic-assisted system. The software is able to create a virtual three-dimensional (3D) model of the patients' knee based on the preoperative CT scan. The surgeon viewed and planned bony cuts, implant sizes, and alignments before the incision was made. Intraoperatively, reflective arrays were placed superior and inferior to the arthrotomy. Bony landmarks were registered with the robotic system creating a dynamic CT-based 3D rendering of the knee allowing assessment of native alignments, flexion, and extension gaps, as well as ranges of motions. The surgeon achieved joint balance by adjusting implant position and alignment virtually, in real time prior to bone cuts. The Mako System (Mako Surgical Corporation [Stryker], Fort Lauderdale, FL) was then used to achieve the planned bony resections. The robotic-assisted system utilizes a haptic window that is aligned with the surgeon's intraoperative adjustments, therefore, constraining the power saw to these virtual boundaries. The robotic arm was brought forward to make the proximal tibiae, femoral condyles, and anterior chamfer resections followed by the posterior chamfers and then the distal femora. Trial components were placed and overall limb alignments, as well as medial and lateral flexion and extension gaps, were assessed objectively.

In both cohorts, cementless cruciate retaining implants (Triathlon Tritanium, Stryker, Mahwah, NJ) were utilized with a cementless asymmetrical patella component. Polyethylene thickness was chosen to optimize range of motion and diminish joint laxity. Before closure, 1 gram of vancomycin powder was administered intra-articularly. A periarticular block consisting of bupivacaine 0.25%, duramorph, toroidal, Depo Medrol (Zoetis Inc., Parsipanny, New Jersey), and epinephrine along with 2 g of tranexamic acid was utilized.

Postoperative care was the same in each group. Patients received inpatient physical therapy sessions beginning on the same day as surgery. Prior to discharge, patients had to have been able to ambulate on flat ground and stairs individually with the use of an ambulating-assistive device (i.e., walker and crutches). Patients were discharged to either home or to a skilled nursing facility depending on patient comorbidities, family statuses, and preferences. If discharged to home, patients were given stretching and light at home exercises to complete each day. Patients followed a standard in office follow-up schedule with appointments at approximately 10 days, 6 weeks, 4 months, 1 year, and 2 years following surgery. At the first postoperative appointment, patients were given an outpatient physical therapy prescription to be completed for 4 to 6 weeks depending on individual progress.

Primary outcomes analyzed included aseptic survivorship rates, 2-year r-WOMAC pain, physical function, and total scores, as well as surgical and medical complications, and postoperative radiographs between the two cohorts. Aseptic survivorship rates over the first 2 years were calculated and included any revision of the tibial, femoral, patellar, and/or polyethylene components. All patients were administered a preoperative and 2-year postoperative r-WOMAC survey. Although 2-year patient follow-up visits were not standard of care, some patients did want to be seen at 2 years after surgery and were administered the survey in the office. Otherwise, they had their surveys administered through electronic mail. Surgical and medical complications were included if the patient required further follow-up, was admitted to the hospital, or underwent additional surgery. This included surgical site infections, deep vein thromboses (DVT), pulmonary emboli, hemarthroses, patellar fractures, manipulations under anesthesia (MUA), irrigation and debridements (I and Ds), arthroscopic synovectomies, and polyethylene exchanges.

Routine anteroposterior, lateral, and patellar radiographs were obtained at each follow-up and reviewed by the senior surgeon (R.C.M.). Alignment, subsidence, and radiolucency was assessed. Progressive radiolucent lines greater than 2 mm (mm) were recorded and assigned to zones using recommended the Knee Society guidelines by location.[23]

Patient demographics, surgical data, postoperative complications, and r-WOMAC scores were collected retrospectively and stored in an Excel spreadsheet (Microsoft, Redmond, WA). Patients were filtered sequentially using the inclusion and exclusion criteria. The means, standard deviations, and ranges of preoperative and 2-year postoperative r-WOMAC pain, physical function, and total scores were calculated. Individual patient scores were used to stratify patients and compare the distribution of scores between the two cohorts. Their baseline demographics and r-WOMAC scores were compared using univariate analyses. Independent samples *t*-tests were used for continuous variables while Pearson's Chi-square tests were performed for categorical variables. Data analyses were performed using SPSS version 24 (International Business Machines Corporation, Armonk, NY) and significant differences were defined as a *p*-value less than 0.05.

Results

The aseptic failure rates for the robotic-assisted and manual cohorts were 1.25 and 5.0% (1/80 vs. 4/80), respectively. In the robotic-assisted cohort, one patient underwent two arthroscopies at 5 and 12 months postoperatively for continued knee stiffness and lack of range of motion. The stiffness continued and the patient subsequently had a polyethylene exchange 24 months postoperatively with no further complications. The patient-reported r-WOMAC pain, physical function, and total scores of 5, 4, and 9 points, respectively, at 2-year postoperatively.

In the manual cohort, two patients' tibial components were placed in valgus and were revised. Of these, one patient suffered prolonged pain and underwent a tibial revision 12 months postoperatively. The patient-reported r-WOMAC pain, physical function, and total scores of 3, 3, and 6, respectively, at 2 years following the initial manual TKA. The second patient did not have pain, but was not aesthetically pleased and had the tibial component revised at 15 months postoperatively with no complications. This patient-reported r-WOMAC pain, physical function, and total scores of 5, 7, and 12 points, respectively, at 2 years following the initial manual TKA. The third patient in the manual cohort suffered a hemarthrosis at 6 weeks postoperatively that required an arthroscopic irrigation. The bleeding persisted and an angiogram and procedure was performed to repair a pseudoaneurysm 2 weeks later. A three-phase bone scan was conducted due to continued pain and discomfort 9 months postoperatively that revealed possible tibial loosening. A subsequent tibial revision was undergone with repair of the lateral retinacular capsule without any further complications. The patient-reported r-WOMAC pain, physical function, and total scores of 7, 11, and 18 points, respectively, at 2 years following the initial manual TKA. Another patient, who had Ehlers–Danlos syndrome, had continued knee instability and underwent a polyethylene exchange 16 months postoperatively. The patient had no further complications and reported r-WOMAC pain, physical function, and total scores of 1, 2, and 3 points, respectively, at 2-year postoperatively.

Two years postoperatively, patients in the robotic-assisted cohort had significantly better r-WOMAC mean pain (1 ± 2 vs. 2 ± 3 points, $p = 0.02$), mean physical function (2 ± 3 vs. 4 ± 5 points, $p = 0.009$), and mean total scores (4 ± 5 vs. 6 ± 7 points, $p = 0.009$) compared with the manual TKA. The mean r-WOMAC pain score for robotic-assisted patients was 1 ± 2 points (range: 0–10), while the mean pain score for the manual cohort was 2 ± 3 points (range: 0–9). The mean physical function scores were 2 ± 3 points (range: 0–14) and 4 ± 5 points (range: 0–28) for the robotic-assisted and manual cohorts, respectively. Also, the mean r-WOMAC total scores were 4 ± 5 points (range: 0–24) and 6 ± 7 points (range: 0–28) for the robotic-assisted and manual TKA groups. The lower scores reported by the robotic-assisted TKA cohort indicated improved 2-year postoperative outcomes (►**Table 3**).

The r-WOMAC pain scores of the robotic-assisted TKA cohort showed a narrower and positively skewed distribution with a greater proportion of patients having lower, improved pain scores. Specifically, 66% of the robotic-assisted patients reported pain scores of either none (0) or mild (1), whereas 50% of the manual patients reported these same outcomes. While there was a larger range of scores in the robotic-assisted group, only six patients (8%) reported pain scores of 5 points or above. In contrast, there were 19 patients (24%) in the manual cohort who reported pain scores of 5 points or higher, indicating a greater amount of pain (►**Fig. 1**).

The distribution of robotic-assisted and manual r-WOMAC physical function scores were relatively similar, although the robotic-assisted histogram had a steeper curve indicating a greater number of patients reporting lower and therefore improved scores. There were 42 robotic-assisted patients (53%) who reported no (0) or mild (1) difficulty with everyday tasks compared with 38 manual patients (48%). A large grouping of patients in the robotic-assisted cohort are seen with a scores below 5 points. More specifically, only 15 robotic-assisted patients (19%) reported scores of 5 points

Table 3 Two-year postoperative r-WOMAC scores

2-year postoperative r-WOMAC	Manual TKA		Robotic-assisted TKA		*p*-Value
	Mean ± SD	Range	Mean ± SD	Range	
Pain	2 ± 3	0–9	1 ± 2	0–10	0.024
Physical function	4 ± 5	0–28	2 ± 3	0–14	0.009
Total	6 ± 7	0–28	4 ± 5	0–24	0.009

Abbreviations: r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; SD, standard deviation; TKA, total knee arthroplasty.
Note: *p*-Values calculated using independent samples *t*-test.

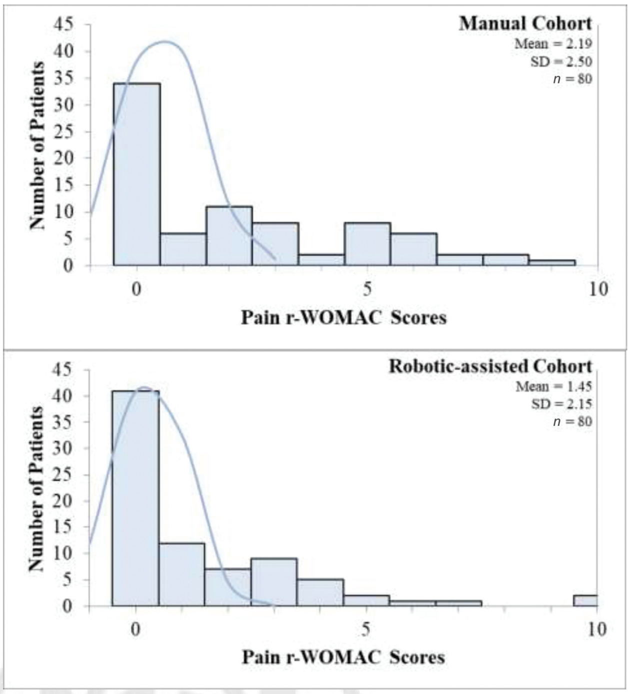

Fig. 1 Distribution curves for 2-year postoperative r-WOMAC pain scores. r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; SD, standard deviation.

or higher, in contrast to 30 manual patients (38%) who reported scores of 5 points or above (►**Fig. 2**).

Compared with the manual patient 2-year postoperative r-WOMAC total scores, the robotic-assisted scores are less distributed and overall lower. The robotic-assisted distribution curve is narrower and steeper than the manual TKA curve with a positive skew. There were a higher percentage of patients who had a total score of either 0 points or 1 point in the robotic-assisted (45%) than in the manual TKA cohort (38%). In addition, 27 robotic-assisted patients (34%) reported scores 5 points and higher, in contrast to 37 manual TKA patients (46%). The trends in generally lower distributions of r-WOMAC scores indicated superior outcomes in the robotic-assisted cohort. (►**Fig. 3**)

There was one medical complication in the robotic-assisted cohort, while there were three in the manual cohort (►**Table 4**). In the robotic-assisted cohort, a patient suffered a DVT and pulmonary embolism 2 months postoperatively and was administered enoxaparin sodium and prescribed apixaban for the next 3 months. This patient was followed by their primary care doctor with no further complications and reported r-WOMAC pain, physical function, and total scores of 5, 5, and 10 points, respectively, at 2-year postoperatively. Within the manual cohort, one patient presented 10 days after surgery with profuse postoperative drainage from the surgical site and was prescribed sulfamethoxazole 500 mg to be taken twice a day for 14 days with no further complications. This patient-reported r-WOMAC pain, physical function, and total scores of 0 points, 1, and 1 point, respectively, at 2-year postoperatively. Another patient developed a hemarthrosis 6 weeks postoperatively that was evacuated in the office with no additional complications. This patient-reported r-WOMAC pain, physical function, and total scores of 1 point, 1 point, and 2 points, respectively, at 2-year postoperatively. Also, a patient fell and suffered a minimally

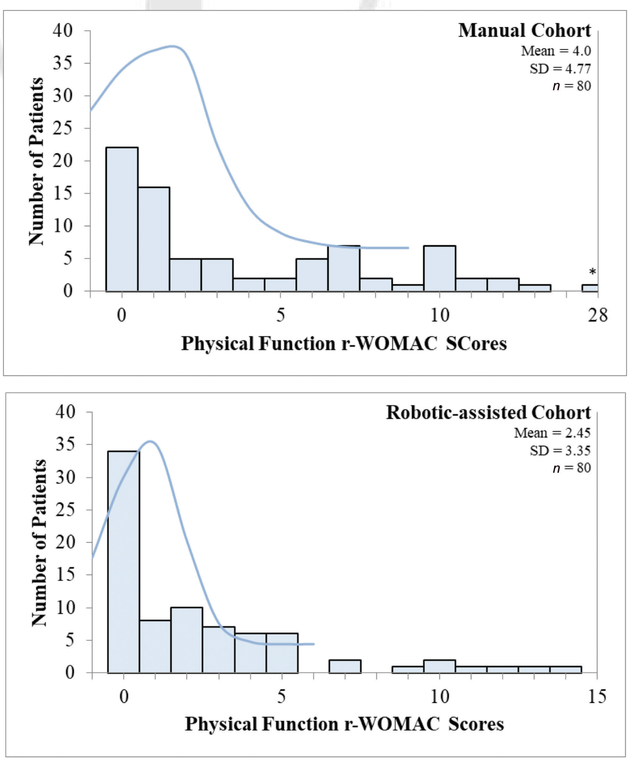

Fig. 2 Distribution curves for 2-year postoperative r-WOMAC physical function scores. r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; SD, standard deviation. *Denotes outliers.

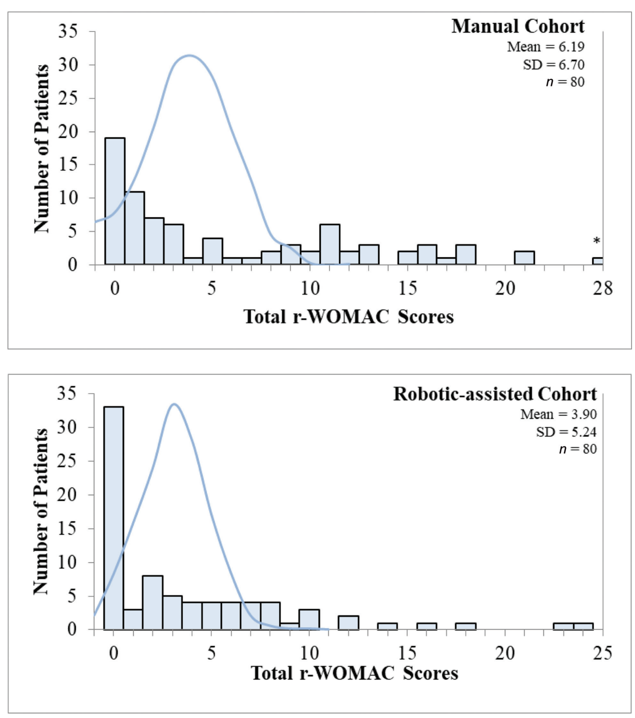

Fig. 3 Distribution curves for 2-year postoperative r-WOMAC total scores. r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; SD = standard deviation. *Denotes outliers.

Table 4 Two-year postoperative medical complications

Complication	Incidence (%)	Post-op timing (mean)	r-WOMAC total score (mean)
Robotic-assisted TKA			
DVT and PE	1 (1.3)	2 months	10
Manual TKA			
Postoperative drainage	1 (1.3)	10 days	1
Hemarthrosis	1 (1.3)	6 weeks	2
Patellar fracture	1 (1.3)	12 months	18

Abbreviations: DVT, deep vein thrombosis; PE, pulmonary embolism; post-op, postoperative; r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; TKA, total knee arthroplasty.

displaced patella fracture 12 months postoperatively. The knee was immobilized, and the fracture healed nonsurgically without any further sequelae. This patient-reported r-WOMAC pain, physical function, and total scores of 6, 12, and 18 points, respectively, at 2-year postoperatively.

There were two surgical complications in the robotic-assisted cohort, while there were five in the manual cohort (►**Table 5**). In the robotic-assisted cohort, a patient developed posterolateral mechanical catching with associated pain and underwent arthroscopic synovectomy with exostosis and cheilectomy at 13 months postoperatively. This patient-reported r-WOMAC pain, physical function, and total scores of 3, 7, and 10 points, respectively, at 2-year postoperatively. Also, a patient had continued stiffness with active flexion of 0 to 90 degrees at 4 months postoperatively. A subsequent MUA was performed with active flexion of 0 to 100 degrees following the procedure. This patient-reported r-WOMAC pain, physical function, and total scores of 0, 2, and 2 points, respectively, at 2-year postoperatively. Within the manual cohort, four patients underwent arthroscopic synovectomies to lyse arthrofibrosis adhesions. One patient presented with active flexion of 0 to 100 degrees at 4 months postoperatively and following the arthroscopy achieved active flexion of 0 to 115 degrees. This patient-reported r-WOMAC pain, physical function, and total scores of 7, 11, and 18 points, respectively, at 2-year postoperatively. The second patient presented with active flexion of 0 to 95 degrees at 5 months postoperatively and following the arthroscopy achieved active flexion of 0 to 110 degrees. This patient-reported r-WOMAC pain, physical function, and total scores of 4, 7, and 11 points, respectively, at 2-year postoperatively. Another patient presented with active flexion of 0 to 95 degrees at 8 months postoperatively and following the arthroscopy achieved active flexion of 0 to 110 degrees. This patient-reported r-WOMAC pain, physical function, and total scores of 3, 10, and 13 points, respectively, at 2-year postoperatively. The last patient presented with active flexion of 0 to 85 degrees at 11 months postoperatively and following the arthroscopy achieved active flexion of 0 to 115 degrees. This patient-reported r-WOMAC pain, physical function, and total scores of 2, 9, and 11 points, respectively, at 2-year postoperatively. Also, in the manual cohort one patient's active flexion was 0 to 90 degrees at 6 weeks postoperatively and a subsequent MUA was performed. Following the procedure, active flexion was 0 to 115 degrees and this patient-reported r-WOMAC pain, physical function, and total scores of 0, 0, and 0 points, respectively, at 2-year postoperatively. Also Radiographic analysis revealed tibial alignment in the coronal axis to be within 3 degrees of varus and valgus in all cases. There were no cases of tibial subsidence or progressive radiolucencies. In the manual cohort, tibial alignment in the coronal axis was greater than 3 degrees of valgus in two cases (2.5%). As previously described, these patients underwent tibial revisions at 12 and 15 months postoperatively. There were no cases of tibial subsidence. Progressive radiolucencies were found in one manual TKA (1.25%). A lucent line was reported in the medial zone and measured approximately 4 mm. As previously described, this patient underwent a tibial revision at 9 months postoperatively.

Table 5 Two-year postoperative surgical complications

Complication	Incidence (%)	Post-op timing (mean)	r-WOMAC total score (mean)
Robotic-assisted TKA			
Arthroscopy	1 (1.3)	13 months	10
MUA	1 (1.3)	4 months	2
Manual TKA			
Arthroscopy	4 (5)	7 months	13
MUA	1 (1.3)	6 weeks	0

Abbreviations: MUA, manipulation under anesthesia; post-op, postoperative; r-WOMAC, reduced Western Ontario and McMaster Universities Osteoarthritis Index; TKA, total knee arthroplasty.

Discussion

The use of robotic-assisted technology in TKA has demonstrated many technical advantages in terms of component placement and alignment when compared with conventional techniques.[9–11,24] Through robotic assistance, surgeons are able to individualize each case to balance the knee and then achieve the plan with purported less soft tissue damage than jig-based TKA.[13,25–28] The consistency and precision that robotic-assisted surgery brings to TKA could potentially correspond to improved patient-reported outcomes and implant survivorship over longer follow-up times. There have been more favorable outcomes with robotic-assisted compared with manual TKA perioperatively,[16] at 6 months,[18] and at 1 year postoperatively.[19] This study has demonstrated improved aseptic survival rates, means for postoperative patient-reported pain and physical function, and comparable medical and surgical complications in robotic-assisted compared with manual TKA at 2 years.

The results of this study are comparable to other reports. Malkani et al[17] evaluated robotic-assisted TKA 2-year postoperative outcomes of 188 patients. Their multicenter analysis evaluated patient-reported outcomes using the Short Form-12 Questionnaire (SF-12), the Forgotten Joint Score (FJS), and the Knee Society functional and knee score (KSS). The SF-12 was subdivided into the mental composite score (MCS) and the physical composite score (PCS). The robotic-assisted TKA patients' mean postoperative SF-12 MCS and PCS scores were both at a mean of 57 points (MCS: range, 42–69 and PCS: range, 41–68 points). The mean FJS was 75 points (range, 14–100), while the mean KSS functional score was 84 points (range, 20–100) and the Knee Score was 92 points (range, 40–100). In addition, two patients (1.06%) had subsequent aseptic revisions and just seven patients (3.7%) had other postoperative complications.[17] Similarly, a recent study evaluated the 2-year rates of MUAs following 188 robotic-assisted and 188 conventional TKAs that were performed by five surgeons.[29] Each surgeons' robotic-assisted cases were compared with the same surgeons' manual TKA cases. The MUA rate in the robotic-assisted TKAs was found to be significantly less than the MUA rate in the manual cohort (1.06 vs. 4.79%, $p = 0.03$). When each individual surgeons' cohorts were evaluated, no surgeon had a higher MUA rate in their conventional cohort than their robotic-assisted cohort. Although the current study had an equivalent MUA rate between the robotic-assisted and manual cohorts (1.25%), both rates were low and the robotic-assisted rate was comparable to what Malkani et al found in their robotic-assisted cohort.[28] Due to the understanding that manipulations are a sign of postoperative knee stiffness, the authors concluded that the robotic-assisted cohort had less stiffness and greater postoperative range of motion.[29] This could indicate that the patients had greater postoperative functionality.

Similarly designed studies have also shown differing results. Yang et al[30] compared 71 autonomously performed robotic and 42 manual TKA's clinical outcomes, radiographic outcomes, and implant survivorships at a mean follow-up of 10 years. There were no significant differences found for the visual analogue scale pain score (1.1 ± 1 vs. 1.2 ± 1, $p = 0.5$), the Hospital of Special Surgery score (88.7 ± 10 vs. 87.2 ± 11, $p = 0.8$), or the WOMAC (7.6 ± 9.4 vs. 11.5 ± 14.5, $p = 0.1$) for the robotic and conventional cohorts, respectively. Additionally, radiographic implant alignment mean values were not found to be significantly different. However, when the authors compared the number of postoperative leg alignment outliers through radiographs, there were significantly more outliers in the conventional TKA cohort ($p < 0.001$). This indicates that the robotic system was potentially more consistent for implant placement.[30] While the authors did not find a significant difference in patient-reported outcomes or complications, the robotic system that was used was the first technology of this kind to be used in orthopaedic surgery. The system also utilized an active-autonomous robotic milling technique that was very different from the robotic-assisted technology used in the present study.[31]

Limitations

This study has some limitations. While the cases were not randomized, the manual cohort consisted of the last manual cases performed by the surgeon after 30 years of completing conventional TKAs. The robotic-assisted cohort consisted of cases performed by the surgeon after only 6 months of using the technology. The two cohorts preoperative r-WOMAC scores and demographic data were not significantly different and therefore this limits the confounding variables. Preoperative comorbidities were not taken into account in our analysis. Future studies should include baseline comorbidities to create matching cohorts. The data consisted of cases from a single surgeon at one center. This may decrease the external validity, thereby limiting the generalizability of our results, but could increase the internal validity of the study. To increase the generalizability, future studies should include multiple surgeons and surgical centers. Despite these limitations, this study is valuable because it demonstrates how new technologies in orthopaedics may optimize patient outcomes with 2 years of follow-up data.

Conclusion

Patients who underwent robotic-assisted TKA had lower aseptic revision rates, reported significantly improved 2-year r-WOMAC scores with comparable complications compared with manual TKAs. It was also noticed that the distribution of r-WOMAC scores for the robotic-assisted cohort was narrower and steeper with a positive skew when compared with the manual cohort. In the pain, function, and total scores, there was a greater proportion of robotic-assisted patients with scores of 0 and 1 point when compared with the manual cohort. This indicated improved r-WOMAC scores and a reduction in outliers for the robotic-assisted cohort. With new medical technologies being established, it is important to continue to evaluate and optimize patient outcomes. This study shows that over the critical 2-year postoperative period, patients may expect improved results with robotic-assisted technology.

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Conflict of Interest

K.B.M. reports personal fees from Stryker Corporation, outside the submitted work. M.A.M. reports personal fees from Stryker Corporation, other from The Journal of Knee Surgery, outside the submitted work.

References

1 Caracciolo B, Giaquinto S. Determinants of the subjective functional outcome of total joint arthroplasty. Arch Gerontol Geriatr 2005;41(02):169–176

2 Bachmeier CJM, March LM, Cross MJ, et al; Arthritis Cost and Outcome Project Group. A comparison of outcomes in osteoarthritis patients undergoing total hip and knee replacement surgery. Osteoarthritis Cartilage 2001;9(02):137–146

3 Collins M, Lavigne M, Girard J, Vendittoli P-A. Joint perception after hip or knee replacement surgery. Orthop Traumatol Surg Res 2012;98(03):275–280

4 Fortin PR, Clarke AE, Joseph L, et al. Outcomes of total hip and knee replacement: preoperative functional status predicts outcomes at six months after surgery. Arthritis Rheum 1999;42(08):1722–1728

5 Hofmann S, Seitlinger G, Djahani O, Pietsch M. The painful knee after TKA: a diagnostic algorithm for failure analysis. Knee Surg Sports Traumatol Arthrosc 2011;19(09):1442–1452

6 Kim KT, Lee S, Ko DO, Seo BS, Jung WS, Chang BK. Causes of failure after total knee arthroplasty in osteoarthritis patients 55 years of age or younger. Knee Surg Relat Res 2014;26(01):13–19

7 Mandalia V, Eyres K, Schranz P, Toms AD. Evaluation of patients with a painful total knee replacement. J Bone Joint Surg Br 2008; 90(03):265–271

8 Toms AD, Mandalia V, Haigh R, Hopwood B. The management of patients with painful total knee replacement. J Bone Joint Surg Br 2009;91(02):143–150

9 Moon YW, Ha CW, Do KH, et al. Comparison of robot-assisted and conventional total knee arthroplasty: a controlled cadaver study using multiparameter quantitative three-dimensional CT assessment of alignment. Comput Aided Surg 2012;17(02):86–95

10 Kim S-M, Park Y-S, Ha C-W, Lim S-J, Moon Y-W. Robot-assisted implantation improves the precision of component position in minimally invasive TKA. Orthopedics 2012;35(09):e1334–e1339

11 Hampp EL, Chughtai M, Scholl LY, et al. Robotic-arm assisted total knee arthroplasty demonstrated greater accuracy and precision to plan compared with manual techniques. J Knee Surg 2019;32 (03):239–250

12 Naziri Q, Cusson BC, Chaudhri M, Shah NV, Sastry A. Making the transition from traditional to robotic-arm assisted TKA: what to expect? A single-surgeon comparative-analysis of the first-40 consecutive cases. J Orthop 2019;16(04):364–368

13 Khlopas A, Chughtai M, Hampp EL, et al. Robotic-arm assisted total knee arthroplasty demonstrated soft tissue protection. Surg Technol Int 2017;30:441–446

14 Liow MHL, Chin PL, Tay KJD, Chia SL, Lo NN, Yeo SJ. Early experiences with robot-assisted total knee arthroplasty using the DigiMatch ROBODOC surgical system. Singapore Med J 2014;55(10):529–534

15 Liow MHL, Goh GSH, Wong MK, Chin PL, Tay DKJ, Yeo SJ. 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

16 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

17 Malkani AL, Roche MW, Kolisek FR, et al. New technology for total knee arthroplasty provides excellent patient-reported outcomes: a minimum two-year analysis. Surg Technol Int 2020; 36:276–280

18 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

19 Marchand RC, Sodhi N, Anis HK, et al. One-year patient outcomes for robotic-arm-assisted versus manual total knee arthroplasty. J Knee Surg 2019;32(11):1063–1068

20 Bellamy N, Buchanan WW, Goldsmith CH, Campbell J, Stitt LW. Validation study of WOMAC: a health status instrument for measuring clinically important patient relevant outcomes to antirheumatic drug therapy in patients with osteoarthritis of the hip or knee. J Rheumatol 1988;15(12):1833–1840

21 Whitehouse SL, Lingard EA, Katz JN, Learmonth ID. Development and testing of a reduced WOMAC function scale. J Bone Joint Surg Br 2003;85(05):706–711

22 Bellamy N, Wilson C, Hendrikz J, et al; EDC Study Group. Osteoarthritis Index delivered by mobile phone (m-WOMAC) is valid, reliable, and responsive. J Clin Epidemiol 2011;64(02):182–190

23 Meneghini RM, Mont MA, Backstein DB, Bourne RB, Dennis DA, Scuderi GR. Development of a modern Knee Society radiographic evaluation system and methodology for total knee arthroplasty. J Arthroplasty 2015;30(12):2311–2314

24 Mont MA, Kinsey T, Zhang J, et al. Robotic-assisted total knee arthroplasty demonstrates greater component placement accuracy compared to manual instrumentation: initial results of a prospective multi-center evaluation. International Society for Technology in Arthroplasty 2019;102-B(01):

25 Sultan AA, Piuzzi N, Khlopas A, Chughtai M, Sodhi N, Mont MA. Utilization of robotic-arm assisted total knee arthroplasty for soft tissue protection. Expert Rev Med Devices 2017;14(12):925–927

26 Kayani B, Konan S, Pietrzak JRT, Haddad FS. 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. J Arthroplasty 2018;33(08):2496–2501

27 Hampp E, Scholl L, Faizan A, Westrich G, Mont MA. Greater Iatrogenic Soft Tissue Damage In Conventional Approach When Compared With The Robotic-Arm Assisted Approach For Total Knee Arthroplasty. [Conference Presentation Abstract]. Nineteenth European Federation of Orthopaedics and Traumatology Congress, Barcelona, Spain;)2018, May 30-June 1)

28 Calliess T, Ettinger M, Savov P, Karkosch R, Windhagen H. Individualized alignment in total knee arthroplasty using image-based robotic assistance : video article. Orthopade 2018;47(10):871–879

29 Malkani AL, Roche MW, Kolisek FR, et al. Manipulation under anesthesia rates in technology-assisted versus conventional-instrumentation total knee arthroplasty. Surg Technol Int 2020; 36:336–340

30 Yang HY, Seon JK, Shin YJ, Lim HA, Song EK. Robotic total knee arthroplasty with a cruciate-retaining implant: a 10-year follow-up study. Clin Orthop Surg 2017;9(02):169–176

31 Liow MHL, Chin PL, Yeo SJ. Total knee arthroplasty technique: tsolution one (Robodoc). In: Lonner JH, ed. Robotics in Knee and Hip Arthroplasty. Switzerland: Springer International Publishing; 2019:195–201

