One-Year Patient Outcomes for Robotic-Arm-Assisted versus Manual Total Knee Arthroplasty

Robert C. Marchand, MD[1] Nipun Sodhi, MD[2] Hiba K. Anis, MD[3] Joseph Ehiorobo, MD[2] Jared M. Newman, MD[4] Kelly Taylor, MD[1] Caitlin Condrey, MD[1] Matthew S. Hepinstall, MD[4] Michael A. Mont, MD[4]

[1] Department of Orthopaedic Surgery, Ortho Rhode Island, Wakefield, Rhode Island
[2] Department of Orthopaedic Surgery, Lenox Hill Hospital Northwell Health, New York, New York
[3] Department of Orthopaedic Surgery, Cleveland Clinic, Cleveland, Ohio
[4] Department of Orthopaedic Surgery, SUNY Downstate Medical Center, Brooklyn, New York

Address for correspondence Michael A. Mont, MD, Department of Orthopaedic Surgery, Lenox Hill Hospital, 100 East 77th Street, New York, NY 10075 (e-mail: mmont@northwell.edu).

J Knee Surg 2019;32:1063–1068.

Abstract

Although there are many studies on the alignment advantages when using the robotic arm–assisted (RAA) system for total knee arthroplasty (TKA), there have been questions regarding patient-reported outcomes. Therefore, the purpose of this study was to use this index to compare: (1) total, (2) physical function, and (3) pain scores for manual versus RAA patients. We compared 53 consecutive RAA to 53 consecutive manual TKAs. No differences in preoperative scores were found between the cohorts. Patients were administered a modified Western Ontario and McMaster Universities Osteoarthritis Index satisfaction survey preoperatively and at 1-year postoperatively. The results were broken down to: (1) total, (2) physical function, and (3) pain scores. Univariate analysis with independent samples *t*-tests was used to compare 1-year postoperative scores. Multivariate models with stepwise backward linear regression were utilized to evaluate the associations between scores and surgical technique, age, sex, as well as body mass index (BMI). Statistical analyses were performed with a $p < 0.05$ to determine significance. The RAA cohort had significantly improved mean total (6 ± 6 vs. 9 ± 8 points, $p = 0.03$) and physical function scores (4 ± 4 vs. 6 ± 5 points, $p = 0.02$) when compared with the manual cohort. The mean pain score for the RAA cohort (2 ± 3 points [range, 0–14 points]) was also lower than that for the manual cohort (3 ± 4 points [range, 0–11 points]) ($p = 0.06$). On backward linear regression analyses, RAA was found to be significantly associated with more improved total (β coefficient [β] −0.208, standard error [SE] 1.401, $p < 0.05$), function (β = 0.216, SE = 0.829, $p < 0.05$), and pain scores (β −0.181, SE = 0.623, $p = 0.063$). The RAA technique was found to have the strongest association with improved scores when compared with age, gender, and BMI. This study suggests that RAA patients may have short-term improvements at minimum 1-year postoperatively. However, longer term follow-up with greater sample sizes is needed to further validate these results.

Keywords
- robotic-arm-assisted TKA
- TKA
- new technologies
- outcomes

received
October 3, 2018
accepted after revision
February 18, 2019
published online
April 8, 2019

DOI https://doi.org/10.1055/s-0039-1683977.
ISSN 1538-8506.

Robotic-arm-assisted (RAA) total knee arthroplasty (TKA) has been shown to potentially have certain pre- and intraoperative advantages over manual techniques.[1,2] Hampp et al[2] used a cadaveric model and compared component positioning errors relative to the preoperative plans using optical tracking and navigation. The group found greater accuracy in 11 out of 12 bone cut measurements when using the robotic arm, and increased precision to plan for all bone cut measurements, when compared with manual TKAs ($p \leq 0.05$). Component placement was also found to be as or more accurate and precise to plan when compared with manual TKA (superior in four of the five measurements; $p \leq 0.05$). In a similar follow-up study, the same group utilized computed tomography (CT) scans and validated the above findings as the RAA cohort was found to have greater accuracy and precision to plan than the manual cohort. This was noted for both tibial components (coronal plane 0.8 vs. 1.0 and sagittal plane 1.4 vs. 1.6 degrees) as well as femoral (coronal plane 0.6 vxs. 2.6, sagittal plane 1.1 vs. 3.7, and axial plane 0.7 vs. 3.4 degrees). Another recent study compared the preoperative coronal alignment and final alignment after surgery in 330 RAA TKAs and found that all patients who had an initial varus or valgus deformity of 7 degrees or less were corrected to neutral ($\leq$ 3 degrees).[1]

Although there are many studies on the potential alignment advantages when using the RAA system, there have been questions regarding patient-reported outcomes. To the best of the authors' knowledge, there has only been one reported study on RAA patient satisfaction.[3] This study compared 6-month Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores of a consecutive series of 20 RAA TKAs with 20 manual TKAs performed by a single surgeon. The authors found significant differences in the RAA cohort for WOMAC pain and total scores when compared with the manual cohort ($p < 0.05$). Mean physical function score was also found to be better for the RAA cohort ($p = 0.055$).

Although the earlier study identified more favorable patient satisfaction outcomes in the RAA cohort, further studies at longer term follow-up and with greater sample sizes are needed to substantiate these results. Therefore, the purpose of this study was to use this index to compare: (1) total, (2) physical function, and (3) pain scores for manual versus RAA patients.

Methods

Study Cohorts

RAA TKAs were performed by a single orthopaedic surgeon at a high-volume institution. After allowing for an appropriate learning curve window (14 RAA TKAs), cases from an initial 6-month period, between September 16, 2016, and March 16, 2017, were evaluated. During this 6-month window, a total of 153 RAA TKAs were performed. Of the 153 patients, 53 completed their 1-year WOMAC survey and were included for analysis. A total of 53 consecutive manual TKAs performed by the same surgeon between April 21, 2015, and December 15, 2015, were used for comparison.

Table 1 Patient characteristics of study cohorts

Characteristic	Manual TKA $N = 53$	Robotic-arm-assisted TKA $N = 53$	*p*-Value
Age (years)	63 ± 8 (45–78)	65 ± 7 (51–87)	>0.05[a]
Sex			
Women (%)	25 (47%)	28 (53%)	>0.05[b]
Men (%)	28 (53%)	25 (47%)	
BMI (kg/m^2)	32 ± 7 (19–63)	33 ± 7 (20–50)	>0.05[a]

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

On univariate analysis, there were no significant differences in preoperative WOMAC total, physical function, and pain scores between the two cohorts (►**Table 1**). Additionally, no significant differences in patient demographics (age, sex, or body mass index [BMI]) were found between the two cohorts (►**Table 2**).

Robotic-Arm-Assisted Total Knee Arthroplasty System Operative Details

Preoperatively, a CT scan–based bone model and surgical plan were reviewed by the surgeon. Intraoperatively, a standard medial parapatellar approach with minimal medial release was performed. Arrays were placed on the tibia and femur, which were used to determine intraoperative joint position. The software allowed for virtual adjustments to the prosthesis by the primary surgeon to identify optimal joint balancing and component alignment prior to bone cuts. The robotic arm was then brought in to make sequential cuts first on the distal femur, posterior chamfer, anterior condyle cuts, anterior chamfer, and finally, the proximal tibia. Implants were then trialed with the knee in flexion and then extension to assess joint stability. After final soft tissue balancing was performed, the implants (Triathlon Cruciate Retaining System, Stryker, Mahwah, NJ) were cemented in place. Final component alignment and patella tracking were checked before wound closure.

Postoperative Rehabilitation

Both the RAA and manual TKA patient cohorts were prescribed the same postoperative rehabilitation protocols. Although specific protocols were unique to each patient, typically patients started their rehabilitation within 1 day after their procedure and began with weight bearing as tolerated. Patients then moved on to stretching exercises, and per patient discretion, were encouraged to start a light strength training program to help build the surrounding muscles. All patients completed the above protocol with a combination of outpatient and at-home physical therapy.

Western Ontario and McMaster Universities Osteoarthritis Index Survey

The WOMAC is a validated hip and knee survey.[4–7] It is a self-administered survey that consists of 24 questions distributed

Table 2 Preoperative WOMAC scores

Preoperative WOMAC scores	Manual TKA		Robotic-arm-assisted TKA		*p*-Value
	Mean ± SD	Range	Mean ± SD	Range	
Total	24 ± 8	7–46	22 ± 8	7–38	0.094
Physical function	14 ± 5	3–26	13 ± 5	3–24	0.084
Pain	10 ± 3	4–20	9 ± 3	2–16	0.077

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

among three subcategories: pain (5 questions), stiffness (2 questions), and physical function (18 questions). Higher WOMAC scores correlate to worse total mobility and function. Both the manual and RAA cohort patients completed these surveys at their preoperative and 1-year postoperative visits.

Although the WOMAC is an arthritis index, it would be expected that patients with higher scores (i.e., worse pain, stiffness, etc.) would have lower satisfaction outcomes as this has been shown to be the case when utilizing other similar indices.[8] Additionally, WOMAC was previously been utilized in the analogous 6-month RAA TKA satisfaction study.[3] Furthermore, Bourne et al[9] and Walker et al[10] also identified the associations between WOMAC scores and satisfactions. We therefore used this index as a surrogate for patient satisfactions.

Pain Scores

Pain was assessed by having patients rank five items on level of difficulty. Patients ranked their pain levels during: (1) walking, (2) using stairs, (3) in bed, (4) sitting or lying, and (5) standing upright. Higher pain scores correlated to higher pain levels. Both the manual and RAA cohort patients completed the pain survey during their 1-year postoperative visits.

Physical Function Scores

The physical function score was calculated by asking patients to assess their ability to: (1) descend stairs, (2) ascend stairs, (3) rise from sitting, (4) stand, (5) bend, (6) walk, (7) get in and out of a car, (8) shop, (9 and 10) put on and take off socks, (11) rise from bed, (12) lie in bed, (13 and 14) get in and out of the bath, (15) sit, (16) get on and off of the toilet, (17) perform heavy domestic duties as well as perform, and (18) light domestic duties. Higher physical function scores correlate to lower physical function abilities. Both the manual and RAA cohort patients completed the physical function survey during their 1-year postoperative visits.

Total WOMAC Score

The total WOMAC score was calculated by taking the sum of the patient's pain and patient's physical function score.

Data Analysis

Baseline patient demographics (age, sex, and BMI) as well as WOMAC scores were compared between the two cohorts with univariate analyses. Independent samples *t*-tests were performed for continuous variables to compare means and Pearson's chi-square tests were performed for categorical variables. Histograms were created to compare the distribution of total, function, and pain WOMAC scores between the RAA and manual cohorts.

Multicollinearity between the study variables were tested with variance inflation factors (VIFs); VIFs greater than three identified strong collinearity. No collinearity was identified between the study covariates; therefore, they were all included in the multivariate regression analyses. Multivariate models with stepwise backward linear regression were utilized to further evaluate the associations of surgical technique with pain, function, and total WOMAC scores. The study covariates analyzed were: surgical technique (manual vs. RAA), age, sex, and BMI. All of these variables were included in the regression model, and variables with the weakest correlations were sequentially removed in subsequent models until that with the strongest association was identified.

All data analyses were performed using SPSS version 22.0 (International Business Machine Corporation, Armonk, NY) and statistical significance was maintained at a *p*-value of less than 0.05.

Results

Total WOMAC Scores

A positive skew was observed with the total WOMAC scores reported in the RAA cohort, as well as a tighter distribution when compared with the manual cohort (►**Fig. 1**). This indicates that there was a greater proportion of patients with lower, and therefore improved total WOMAC scores in the RAA cohort.

One-year postoperative total WOMAC scores were significantly lower in the RAA cohort ($p < 0.05$) compared with the manual cohort, indicating overall improved outcomes for RAA patients (►**Table 3**). The mean total WOMAC score for the manual cohort was 9 ± 8 points (range, 0–27 points), while the mean total score for the RAA cohort was 6 ± 6 points (range, 0–29 points).

On backward regression analyses, RAA was found to be significantly associated with lower total WOMAC scores (β coefficient [β] −0.208, SE 1.401, $p < 0.05$) at 1-year postoperatively. Specifically, in each stepwise model, the use of the RAA surgical technique was found to have the strongest association with total WOMAC scores when compared with age, gender, and BMI.

Physical Function Scores

Compared with the manual cohort, a greater number of patients in the RAA cohort reported lower, and therefore improved function scores (►**Fig. 2**). The histograms showed a more positive skew with the RAA than manual cohort.

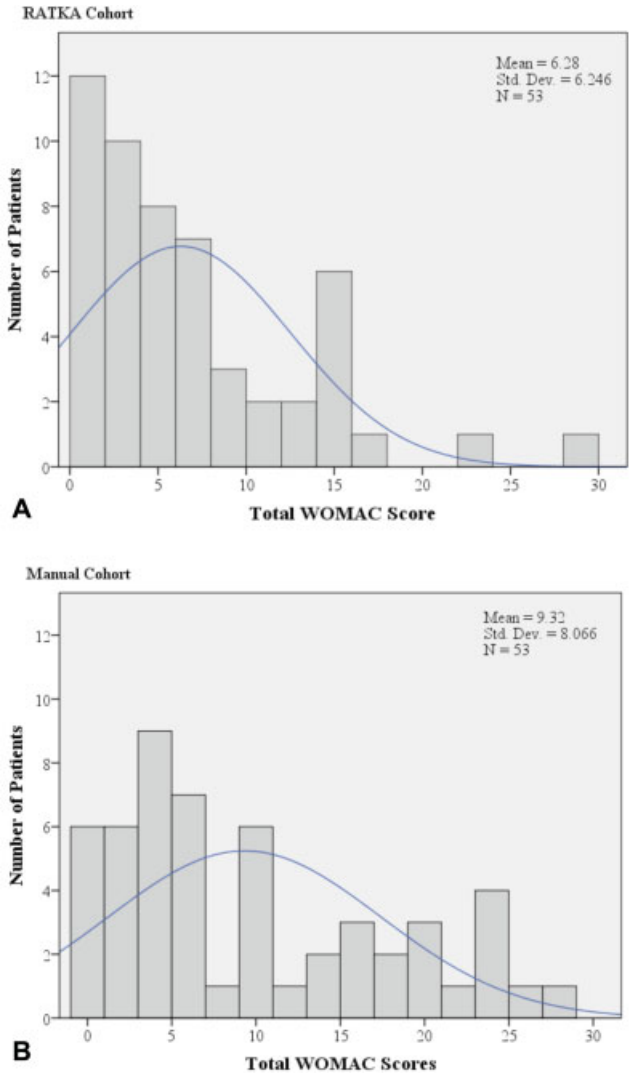

Fig. 1 Distribution curves of 1-year postoperative total WOMAC (Western Ontario and McMaster Universities Osteoarthritis) scores. RATKA, robotic-arm-assisted total knee arthroplasty.

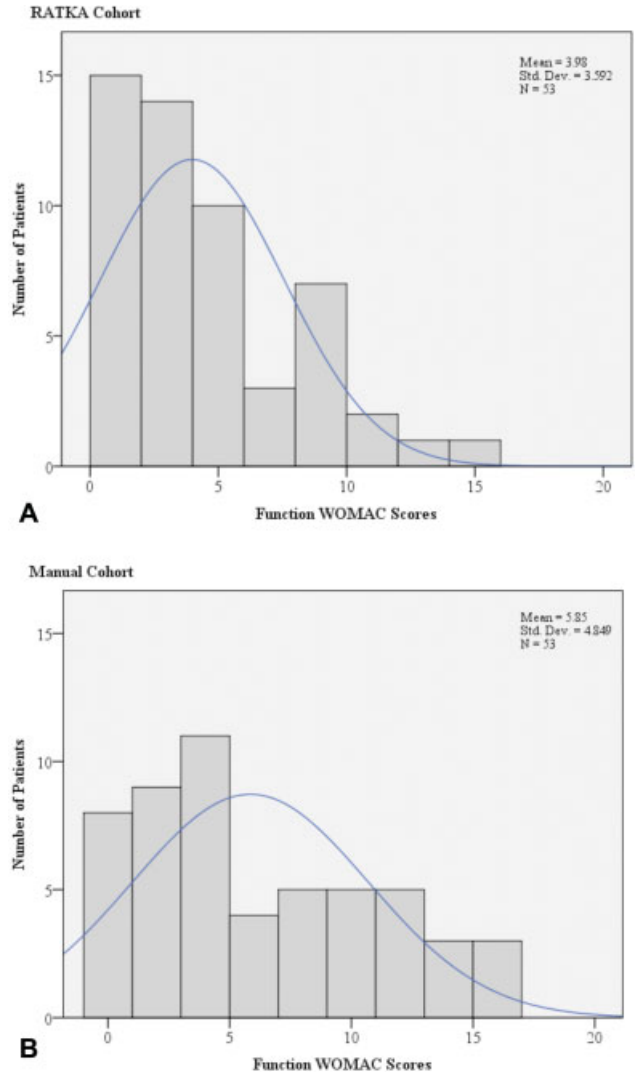

Fig. 2 Distribution curves of 1-year postoperative function WOMAC (Western Ontario and McMaster Universities Osteoarthritis) scores. RATKA, robotic-arm-assisted total knee arthroplasty.

For the manual cohort, the mean physical function score was 6 ± 5 points (range, 0–16 points), whereas the mean physical function score for the RAA cohort was 4 ± 4 points (range, 0–15 points; $p < 0.05$; ►**Table 3**), indicating better physical function outcomes for RAA patients.

Multivariate backward regression also found the use of RAA TKA to have a significant association (β −0.216, SE 0.829, $p < 0.05$) with lower and therefore improved function scores 1 year postoperatively. Specifically, in each stepwise model, the use of the RAA surgical technique was found to have the strongest association with WOMAC function scores when compared with age, gender, and BMI.

Pain Scores

Overall, there was a greater proportion of patients with lower pain scores in the RAA cohort compared with the manual cohort (►**Fig. 3**). More specifically, more than 75% of the RAA patients had a pain score of 3 points or lower,

Table 3 One-year postoperative WOMAC scores

1-year postoperative WOMAC scores	Manual TKA		Robotic-arm-assisted TKA		*p*-Value
	Mean ± SD	Range	Mean ± SD	Range	
Total	9 ± 8	0–27	6 ± 6	0–29	**<0.05**
Physical function	6 ± 5	0–16	4 ± 4	0–15	**<0.05**
Pain	3 ± 4	0–11	2 ± 3	0–14	0.06

Abbreviations: SD, standard deviation; TKA, total knee arthroplasty; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
Note: *p*-Values: independent samples *t*-test. Bold is used to identify significant values ($p < 0.05$).

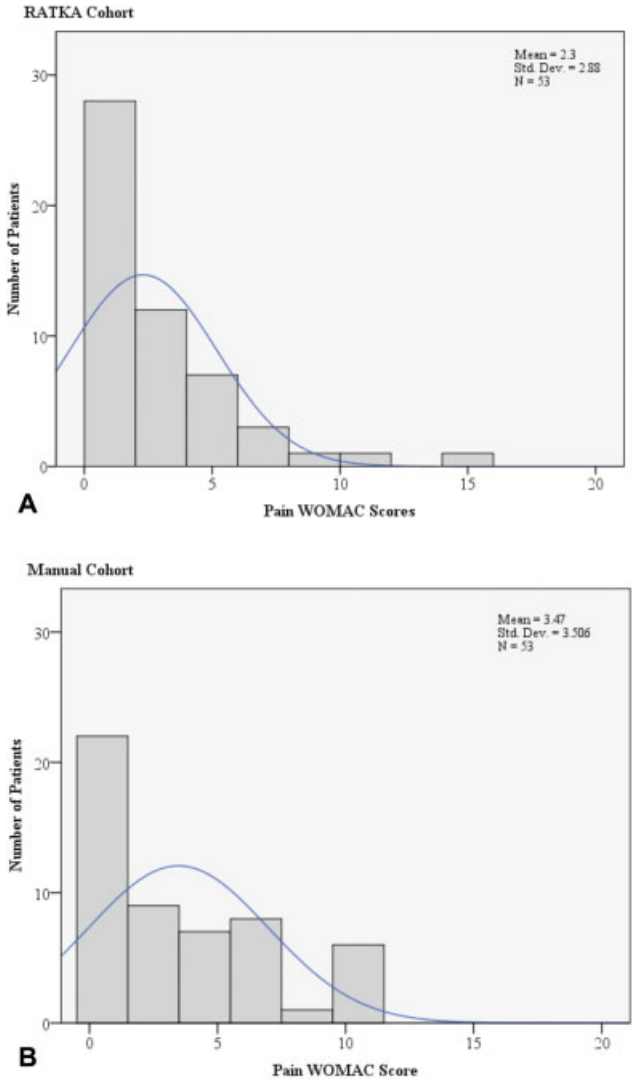

Fig. 3 Distribution curves of 1-year postoperative pain WOMAC (Western Ontario and McMaster Universities Osteoarthritis) scores. RATKA, robotic-arm-assisted total knee arthroplasty.

whereas, more than 50% of the manual patients had a pain score of 3 points or greater.

The mean postoperative pain score for the manual cohort was found to be 3 ± 4 points (range, 0–11 points), whereas the mean postoperative pain score for the RAA cohort was found to be lower at 2 ± 3 points (range, 0–14 points; $p = 0.06$; ►**Table 3**).

Of all the study covariates included in the model, the use of RAA had the strongest association (β −0.181, SE = 0.623, $p = 0.063$) with lower pain scores. Specifically, in each stepwise model, the use of the RAA surgical technique was found to have the strongest association with WOMAC pain scores when compared with age, gender, and BMI (►**Table 4**).

Discussion

RAA TKA has been shown in the literature to potentially improve several clinical, radiographic, and operative factors.[11–14] However, patient satisfaction outcomes are arguably one of the most important outcomes, and should remain at the center of analysis. While 6-month RAA patient satisfaction outcomes have been reported to be favorable, longer term follow-up with larger cohorts is needed to substantiate the earlier results. Therefore, the purpose of this study was to assess 1-year patient satisfaction outcomes in RAA versus manual TKA patients. The results of this study continue to highlight RAA patient outcomes when compared with manual techniques.

Table 4 Association between the use of RAA surgical technique and WOMAC scores

1-year postoperative WOMAC scores	Standardized coefficient (β)	Standard error (SE)	*p*-Value
Total	−0.208	1.401	**<0.05**
Physical function	−0.216	0.829	**<0.05**
Pain	−0.181	0.623	0.063

Abbreviations: RAA, robotic-arm-assisted; SE, standard error; WOMAC, Western Ontario and McMaster Universities Osteoarthritis Index.
Note: Bold is used to identify significant values ($p < 0.05$).

Several factors may contribute to the results noted from this study. Due to the haptic saw blade and real-time, intraoperative feedback, the RAA system can help protect surrounding soft tissues by preventing the blade from cutting outside of the desired field.[15] Furthermore, the CT scan–based patient-specific three-dimensional joint rendering has been shown to enhance preoperative planning.[16] These reasons, as well as potentially many others, are likely to contribute to the 1-year outcome results in RAA patients.

There were limitations to this study. This retrospective, single surgeon study focused on early, 1-year outcomes, with a relatively small sample size; therefore, longer term follow-up of larger cohorts is needed. However, as this technology continues to grow and be implemented in many more hospitals and institutions, larger sample sized, prospective, multicenter studies can be performed with additional satisfaction assessment modalities. Furthermore, although this study accounted for some patient-specific factors (i.e., age, sex, and BMI), future studies should also take into account for patient complexities and comorbidities. Nevertheless, these results still provide the basis for future work to build upon.

Similar to this study, other studies have also found robotic technology to be beneficial for TKA patients. Although these are older studies that used a different robotic device utilized in this study, their results are still potentially relevant. Liow et al[17] performed a evaluated 60 knees (31 robotic and 29 manual), and found the robotic cohort to have better Short Form (SF)-36 vitality ($p = 0.03$) and role emotional ($p = 0.02$) outcomes, as well as a larger number of patients reaching SF-36 vitality minimum clinically important difference (48 vs. 14%, $p = 0.009$) than the manual cohort. Additionally, Kim et al[18] evaluated 32 RAA patients, and found Knee Society scores significantly improved postoperatively (27–82.8, $p < 0.001$).

Kayani et al[19] compared 40 consecutive manual TKA versus 40 consecutive RAA patients, evaluating postoperative functional outcomes and time to hospital discharge between the cohorts. The authors found RAA patients had significantly reduced postoperative pain ($p < 0.001$), decreased analgesia requirements ($p < 0.001$), decreased reduction in postoperative hemoglobin levels ($p < 0.001$), shorter time to straight leg raise ($p < 0.001$), decreased number of physiotherapy sessions ($p < 0.001$), and improved maximum knee flexion at discharge ($p < 0.001$) compared with manual TKA patients. Furthermore, RAA patients had significantly shorter time to discharge than manual TKA patients.

Conclusion

With newer surgical technologies constantly being introduced, it is imperative to continue to evaluate these new modalities, particularly in their abilities to improve patient satisfaction outcomes. To the best of our knowledge, this is the first study evaluating 1-year patient satisfaction outcomes utilizing this new RAA TKA. The 1-year postoperative patient satisfaction results from this study corroborate those of an earlier report on 6-month outcomes. Based on these combined outcomes, patient can expect superior early satisfaction from RAA TKA.

Conflict of Interest
Marchand: Stryker
Hepinstall: AAOS, Corin U.S.A., KCI, Stryker
Mont: AAOS, Cymedica, DJ Orthopaedics, Johnson & Johnson, Journal of Arthroplasty, Journal of Knee Surgery, Microport, National Institutes of Health (NIAMS & NICHD), Ongoing Care Solutions, Orthopedics, Orthosensor, Pacira, Peerwell, Performance Dynamics Inc, Sage, Stryker: IP royalties, Surgical Technologies International, Kolon TissueGene

References

1 Marchand RC, Sodhi N, Khlopas A, et al. Coronal correction for severe deformity using robotic-assisted total knee arthroplasty. J Knee Surg 2018;31(01):2–5
2 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 2018. Doi: 10.1055/s-0038-1641729
3 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
4 Jauregui JJ, Banerjee S, Cherian JJ, Elmallah RD, Mont MA. Rating systems to assess the outcomes after total knee arthroplasty. Surg Technol Int 2015;26:289–294
5 Pierce TP, Elmallah RD, Cherian JJ, Jauregui JJ, Mont MA. Standardized questionnaire time burden for practitioners and patients. Surg Technol Int 2015;26:302–306
6 Chughtai M, Khlopas A, Thomas M, et al. Development of an encompassing questionnaire for evaluating the outcomes following total knee arthroplasty. Surg Technol Int 2017;30:306–313
7 Chughtai M, Khlopas A, Mistry JB, Gwam CU, Elmallah RK, Mont MA. Time burden of standardized hip questionnaires. Surg Technol Int 2016;28:280–284
8 Baker PN, van der Meulen JH, Lewsey J, Gregg PJ; National Joint Registry for England and Wales; Data from the National Joint Registry for England and Wales. The role of pain and function in determining patient satisfaction after total knee replacement. J Bone Joint Surg Br 2007;89(07):893–900
9 Bourne RB, Chesworth BM, Davis AM, Mahomed NN, Charron KDJ. Patient satisfaction after total knee arthroplasty: who is satisfied and who is not? Clin Orthop Relat Res 2010;468(01):57–63
10 Walker LC, Clement ND, Bardgett M, et al. The WOMAC score can be reliably used to classify patient satisfaction after total knee arthroplasty. Knee Surg Sports Traumatol Arthrosc 2018;26(11): 3333–3341
11 Schiraldi M, Bonzanini G, Chirillo D, de Tullio V. Mechanical and kinematic alignment in total knee arthroplasty. Ann Transl Med 2016;4(07):130
12 Cherian JJ, Kapadia BH, Banerjee S, Jauregui JJ, Issa K, Mont MA. Mechanical, anatomical, and kinematic axis in TKA: concepts and practical applications. Curr Rev Musculoskelet Med 2014;7(02): 89–95
13 Berend ME, Ritter MA, Meding JB, et al. Tibial component failure mechanisms in total knee arthroplasty. Clin Orthop Relat Res 2004;(428):26–34
14 Sikorski JM. Alignment in total knee replacement. J Bone Joint Surg Br 2008;90(09):1121–1127
15 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
16 Liow MHL, Goh GS, Wong MK, Chin PL, Tay DK, 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
17 Liow MHL, Goh GS-H, Wong MK, Chin PL, Tay DK-J, Yeo S-J. 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
18 Kim K-I, Kim D-K, Juh H-S, Khurana S, Rhyu K-H. Robot-assisted total knee arthroplasty in haemophilic arthropathy. Haemophilia 2016;22(03):446–452
19 Kim K-I, Kim D-K, Juh H-S, Khurana S, Rhyu K-H. Robot-assisted total knee arthroplasty in haemophilic arthropathy. Haemophilia 2016;22(03):446–452