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Original Research

No Difference in Range of Motion, Components, or Complications Following Conversion of Robotic-Assisted Total Knee Arthroplasty Compared to Manual TKA After Undergoing Manual or Robotic-Assisted Unicompartmental Knee Arthroplasty

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A R T I C L E I N F O

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Background: Conversion surgery from unicondylar knee arthroplasty (UKA) to total knee arthroplasty (TKA) remains a challenge due to scarring, implant/cement removal, and loss of bony landmarks. Robotic-assisted (RA) TKA may assist in challenges seen in manual conversion TKA. The aim of this study is to identify if there are differences in components and functional outcomes dependent on manual/RA primary UKA and conversion TKA.
Methods: A retrospective chart review was performed on patients undergoing conversion from UKA to TKA over a 10-year period at a single institution. Data extracted included surgical technique, reason for UKA failure, range of motion at 1 year, need for augments, and utilization of revision components.
Results: Forty-nine patients (50 knees) with a UKA converted to a TKA were divided into 4 groups based on primary and conversion surgery: manual-to-manual ($n = 11$), manual-to-robot ($n = 11$), robot-to-manual ($n = 11$), and robot-to-robot ($n = 17$). There was no difference in need for augments ($P = .376$), size of poly ($P = .23$), postoperative flexion ($P = .52$), or extension ($P = .76$) at 1 year between the 4 groups. However, patients with primary manual UKA did require significantly more augments during revision ($P = .032$).
Conclusions: Our study did not show any statistically significant differences of primary RA or manual UKA to RA or manual TKA in terms of range of motion at 1 year, complications, or differences in components. RA conversion from UKA to TKA is a new but equivalent technique to manual conversion. Primary surgery may impact the requirement for augments during conversion surgery.

Introduction

The incidence of unicondylar knee arthroplasty (UKA) has increased dramatically since the 1990s, peaking around 2008, and represents a significant percent of patients undergoing all knee arthroplasty procedures [1,2]. However, failure of UKA and conversion to total knee arthroplasty (TKA) remains a significant concern for arthroplasty surgeons and patients, with revision surgery rates as high as 40.4% [3]. Conversion surgery from UKA to TKA remains a challenge due to scarring, implant and cement removal, and loss of bony landmarks [4]. This has led to increased use of supplementary fixation stems and augments and may necessitate a higher degree of implant constraint. Manual TKA utilizes intramedullary alignment guides based on external landmarks, making femoral resection a challenge from the previous femoral cut [5,6]. These challenges may help explain why larger polyethylene sizes have been used in manual conversion from UKA to TKA [7,8].

There is a sparsity of literature regarding the conversion of UKA to TKA utilizing robotic-assisted (RA) surgery, as it remains off-label. With one case report showing success of RA-TKA conversion [9], one limited case series found decreased use of augments and a smaller average polyethylene insert in patients undergoing conversion RA TKA compared to manual TKA [10]. One of the difficulties of robotic conversion of UKA to TKA is that robotic assisted surgery requires a preoperative computed tomography (CT) scan in

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which a previous UKA may obscure some of the image, making the edge of the bone difficult to identify during preoperative planning. As there is a paucity of literature on the subject, there is no evidence that there is a difference in outcomes between manual or RA UKA to TKA conversion.

We hypothesize that robotic assisted conversion TKA will decrease the need for augments and decrease the need for a polyethylene component larger than baseline compared to patients who had undergone manual conversion TKA in patients that had undergone either a manual or robotic assisted UKA.

Material and methods

Institutional review board approval was obtained prior to initiation of this study. Patients eligible for this study were identified through a retrospective review of electronic health records for individuals undergoing conversion from UKA to TKA from January 1, 2012, to December 31, 2021, at a single institution by 4 different surgeons. Inclusion criteria were adult patients ($\geq$18 years old) who underwent a conversion from UKA to TKA with at least 1 year of follow-up. Patients were excluded from the study if they did not meet the above criteria. Manual UKA utilized the Zimmer Biomet Oxford Partial Knee System (Warsaw, IN), while manual TKA utilized the Zimmer Biomet Persona system (Warsaw, IN). All robotic UKA and TKAs were performed with the Stryker Mako System CT-based RA technology and utilized Stryker implants including the Restoris MCK for UKA and the Triathlon for TKA (Stryker, Mako, Kalamazoo, MI).

Data collection

All data was compiled and reviewed by the investigators via accessing the patient's Electronic Medical Record with their Medical Record Number. Data extracted from the patient's chart included demographics, date of primary and revision surgery, laterality, physical exam findings such as range of motion (ROM), and reason for UKA failure. Surgical data was collected from the operative report including whether primary and revision surgery was performed manually vs with robotic assist, implant type, need for augmentation, and utilization of revision components (cones, stems, or sleeves). Complications included any patients requiring manipulation under anesthesia (MUA), having an infection, having a ROM less than 90 degrees at long-term follow-up, or requiring secondary revision surgery.

Statistical analysis

Univariate analysis was performed comparing outcomes in patients with primary manual vs robotic UKA and revision manual vs robotic using the chi-square test with alpha set at 0.05. Between-treatment group differences are tested using one-way analysis of variance. When the analysis of variance F-test is significant, Tukey post hoc pairwise comparisons are made to determine the specific treatment groups that differ significantly from each other. Significant Kruskal-Wallis tests are followed up with pairwise comparisons using Dunn's method. Finally, between-group differences in the percent of patients with augments under each exposure are tested using Fisher's exact test.

The analysis is performed first on all of the data and then repeated on the subset of aseptic patients. All statistical tests were assigned an α value of 0.05 and performed using RStudio 1.4 (RStudio, Boston, MA). The largest effect size was observed for the poly above baseline outcome, with Cohen's $f = 0.36$. Given this effect size, the study would have needed to enroll N = 92 subjects to achieve power equal to 0.80 with alpha set at 0.05. Given the rare nature of the procedure, this large sample size was not feasible.

Results

From January 1, 2012, to March 31, 2022, 49 patients (50 knees) who underwent conversion from UKA to TKA at a single institution were identified and met inclusion criteria. Average age of all patients is 57 ± 8 ($P = .413$) with average body mass index (BMI) of 33 ± 9 ($P = .736$). Twenty patients (41%) were male ($P = .739$). The primary causes of failure were aseptic loosening (60%), followed by instability (10%), progression of disease (10%), polyethylene dislocation (4%), infection (2%), or other causes (14%). Specific breakdown by primary and revision surgery are outlined ($P = .335$) (Table 1).

There was no significant difference in flexion ($P = .424$) or extension ($P = .768$) at 1 year, size of poly ($P = .563$), and polyethylene size above baseline ($P = .130$) utilizing parametric testing between the 4 groups (Table 2). Based on the post hoc tests, the only pairwise comparison for polyethylene above baseline that yielded the overall significant result was between manual-to-robot and robot-to-manual, with the former having significantly higher scores than the latter, $P = .023$. Among the 25 aseptic loosening cases, no significant difference in flexion ($P = .409$) or extension ($P = .839$) at 1 year, size of poly ($P = .808$), and poly above baseline ($P = .241$) were identified utilizing parametric testing between the 4 groups (Table 3). Nonparametric testing also resulted in no significant findings.

The data on augments was also tested between groups for the whole sample and the aseptic loosening cases only. Neither was significant. The P-value from Fisher's exact test was .376 in the whole sample and 0.194 in the subsample. Requirements for augments, revision components, and complications were documented (Table 4). Overall, augments were used in 36% of patients with 60%

Table 1
Demographics.

	Manual-manual	Manual-robotic	Robotic-manual	Robotic-robotic	P-value
	N = 11	N = 10	N = 11	N = 17	
Patient characteristics					
Sex	3 (27%)	5 (50%)	5 (45%)	6 (35%)	.739
Age	54 ± 5	59 ± 12	55 ± 6	58 ± 7	.418
BMI	32 ± 15	34 ± 6	35 ± 8	32 ± 6	.736
Reason for UKA failure					.335
Aseptic loosening	4	7	8	11	
Infection	0	0	1	0	
Disease progression	1	2	0	2	
Instability	1	0	1	3	
Poly dislocation	2	0	0	0	
Other	3	2	1	1	

P-values for sex and age from one-way analysis of variance. P-values for sex and UKA failure reason from Fisher exact tests.

Table 2
Summary of outcomes: all data.

Treatment	Mean	SD	Analysis of variance	Kruskall-Wallis
			P-value	*P*-value
Extension at 1 y (deg)			.77	.76
Manual to manual	0.45	1.51		
Manual to robot	1.67	2.89		
Robot to manual	1.82	6.03		
Robot to robot	0.59	2.43		
Flexion at 1 y (deg)			.42	.52
Manual to manual	117.27	11.04		
Manual to robot	120	10		
Robot to manual	120	12.85		
Robot to robot	123.53	5.8		
Poly above baseline (mm)			.13	.040
Manual to manual	1.82	2.14		
Manual to robot	5.33	1.53		
Robot to manual	1	1.9		
Robot to robot	2.41	1.18		
Size of poly (mm)				
Manual to manual	11.64	2.16	.56	.23
Manual to robot	14.33	1.53		
Robot to manual	10.73	1.9		
Robot to robot	11.41	1.18		

Manual to manual $n = 11$. Manual to robot $n = 11$. Robot to manual $n = 11$. Robot to robot $n = 17$.

requiring revision components. Only one patient required a constrained condylar knee, and they were converted from robotic UKA to manual TKA. Complications were documented in 10% of patients with the highest in the manual-robot group (18%). One robotic-manual conversion required 2 MUAs, while one patient undergoing manual-robotic and one robotic-robotic needed MUA. One manual-manual patient required revision surgery due to infection.

Significantly fewer augments were utilized for patients undergoing conversion TKA, regardless of technique, who had a primary UKA that was robotic assisted ($P = .032$) (Table 5). There was no difference in augments based on TKA ($P = .83$) technique or revision components in UKA ($P = .91$) or TKA technique ($P = .64$).

Table 3
Summary of outcomes: aseptic only.

Treatment	Mean	SD	Analysis of variance	Kruskall-Wallis
			P-value	*P*-value
Extension at 1 y (deg)			.83	.94
Manual to manual	1.25	2.5		
Manual to robot	0	0		
Robot to manual	2.5	7.07		
Robot to robot	0.91	3.02		
Flexion at 1 y (deg)			.41	.41
Manual to manual	118.75	6.29		
Manual to robot	125	7.07		
Robot to manual	116.88	13.35		
Robot to robot	124.09	6.64		
Poly above baseline (mm)			.24	.055
Manual to manual	1	1.15		
Manual to robot	6	1.41		
Robot to manual	1	2.07		
Robot to robot	2.45	1.13		
Size of poly (mm)			.81	.26
Manual to manual	10.75	0.96		
Manual to robot	15	1.41		
Robot to manual	10.88	2.1		
Robot to robot	11.45	1.13		

Manual to manual $n = 4$. Manual to robot $n = 7$. Robot to manual $n = 8$. Robot to robot $n = 11$.

Discussion

Overall, there was no significant difference between the 4 groups in terms of postoperative extension and flexion, polyethylene size, or need for augments. Demographic and reason for failure was similar among all patients. Notably, size above normal polyethylene was significantly different with manual to robotic assisted having the largest increase in poly size. These results are contrary to our hypothesis that robotic assisted conversion would allow for more precise surgery leading to decreased use of augments and decreased need to use a larger than baseline poly.

Conversion TKA from failed UKA is more technically challenging than primary surgery with higher re-revision rates from UKA to TKA compared to primary TKA [11-13]. Several complicating factors include need for cement removal, bone loss, loss of typical surgical landmarks, and changes in restoring component alignment. Need for revision stems and augments from conversion UKA to TKA has varied widely including 30%-54% for manual conversion UKA to TKA [7,14], potentially due to bone loss during conversion [13], with larger polyethylene components and more constrained use compared to primary TKA [8]. Thus, improvements in conversion procedures, including the potential benefit of RA surgery, are required.

RA conversion TKA is yet to be approved by the Food and Drug Administration, with concerns that previous hardware will obscure CT preoperative planning, but has been successful. Kalavrytinos et al. [9] first presented RA conversion of failed UKA to TKA with accurate resection and implant positioning. Wallace et al. reported on 4 RA conversions of UKA to TKA, finding that RA conversion led to accurate intraoperative bone cuts and preserved bone stock [15]. Yun et al. [10] found RA conversion TKA required significantly fewer augments and a nonsignificant decrease in polyethylene thickness. Tuecking et al. [16] found imageless RA conversion from UKA to TKA to be a precise technique and may avoid potential obscuration of previous implants from preoperative CT image-guided RA surgery. However, findings of this study and other RA conversion/revision surgery suggest any potential obscuration has minimal to no effect on patient outcomes [9,10,15].

Several publications suggest that RA-TKA may show favorable alignment to conventional TKA [17-19], thus it would also be reasonable that RA conversion surgery may also show favorable component alignment. Independent adjustments of 0.5 degrees or 0.5 mm can still be made to help preserve bone stock while working to maintain joint line. Hypothetically, improved alignment in RA revision surgery would lead to decreased need for revision components, smaller polys, and fewer augments compared to manual revision, as demonstrated in Yun et al. [10]. While previous studies have shown manual conversion from UKA to TKA has increased polyethene sizes compared to primary TKA, our patients generally had similar poly size to a normal primary TKA besides the manual to robot group, which had significantly higher polys compared to baseline [7,8]. This discrepancy is not entirely clear, but with poly sizes comparable in robotic to robotic conversion, we would favor differences in the systems themselves in converting from a Zimmer UKA to Stryker RA-TKA, which led to larger polys in the manual-robot group. While we hypothesized manual revision surgery would require larger poly sizes due to less precision from intramedullary alignment and altered bony landmarks, our study did not find evidence that primary UKA technique altered polyethylene size.

Tuecking et al. found 10% of conversion cases required a semi-constrained insert, comparable to previous reports that found constrained implants were used in 4.2%-10.4% of UKA to TKA conversions [8]. Both of these results showed higher levels of constraint than utilized in any groups of our study, as there

Table 4
Augments and revision components.

Treatment	Manual-manual (n = 11)	Manual-robotic (n = 11)	Robotic-manual (n = 11)	Robotic-robotic (n = 17)
Augments	5 (45%)	6 (54%)	2 (18%)	5 (29%)
Constrained condylar knee	0 (0%)	0 (0%)	1 (9%)	0 (0%)
Revision components	6 (54%)	7 (63%)	8 (73%)	9 (53%)
Complications	1 (9%)	2 (18%)	1 (9%)	1 (6%)
MUA	0 (0%)	1 (9%)	1 (9%)	1 (9%)
Need for 2nd revision	1 (9%)	0 (0%)	0 (0%)	0 (0%)

was only one patient in the robotic-manual group with a constrained condylar knee implant.

The results of our study also demonstrated no statistically significant differences when looking only at revisions in cases of aseptic loosening. UKA loosening may produce wear-induced osteolysis, leading to subsidence [20]. This osteolysis and subsidence may negate some of the benefits of RA revision compared to manual conversion, as less bone can be conserved. Aseptic loosening was overrepresented in this study compared to previous reports on failure mechanisms [12,21], likely due to the high BMI of our patient population. Previous studies did not report BMI; however, differences in patient outcomes due to demographics may highlight the impact of patient selection on who may most benefit from RA conversion [10]. Additionally, these results suggest that etiology of revision may play a role in the benefits of RA conversion surgery.

Index UKA technique may impact need for augments, while revision procedure may not. Significantly fewer RA UKA patients required augments upon revision compared to manual. However, there was no difference in the need for augments or revision components depending on RA or manual conversion TKA. Robotic UKA is theoretically more precise than manual UKA [22], potentially allowing for more bone to be conserved during conversion to TKA regardless of conversion technique. Alternatively, different techniques between primary and conversion surgery may be considered in outcomes. Manual-robotic and robotic-manual conversion groups had the highest levels of revision components utilized at 73% and 63% of patients, with one patient in each group with stiffness requiring postoperative MUA.

While the sample size is small and these results were not statistically significant, the worst outcomes came in patients with strictly manual TKA. One patient required revision due to infection, while 2 patients only obtained ROM from 0-90 and 20-90 degrees at 1 year. Manual-robot did have the most complications in one patient, although this was from a reoperation due to cement prominence, which does not appear to be related to the method of conversion itself. ROM remains a problem in conversion TKA, as stiffness can be increased in patients with conversion UKA to TKA compared to primary TKA [13]. Scarring and thickening of the joint capsule decrease ROM after multiple knee arthroplasties. While there was no statistical difference between the 4 groups, patients in the robotic revision groups did have a few degrees more of flexion and extension. Of the patients undergoing manual conversion, one patient had postoperative stiffness requiring MUA twice, while there were 2 patients in the robotic revision group requiring MUA. With the goal of postoperative active range of motion generally around 110 degrees for symmetrical stair gait [23], only one patient in the robot group did not reach this mark after MUA, although it was 105 degrees. Comparatively, 3 of the manual conversion group did not reach 110 degrees at 1-year follow-up with 2 patients only reaching 90 degrees of flexion, suggesting increased stiffness. Chronic inflammation may lead to fibrosis, knee stiffness, and limited ROM after revision TKA [24,25]. RA-TKA has been found to have a reduction in the early postoperative local inflammatory response [26]. Decreased IL-6 and IL-8 levels were found in the early perioperative period after RA-TKA compared to manual, which correlated with reduced pain scores. This is thought to be reflective of reduced bone and soft tissue injury from multiple cuts or the lack of intramedullary referencing. Decreased pain and inflammation is thought to lead to faster recovery and shorter length of stay [27,28]. Inflammation is also tied to poor wound healing and increased risk of infection in several conditions [29], which may further impact patient recovery and complications following revision TKA [27,28]. Thus, there is some evidence that revision TKA utilizing the robot in our patient population may minimize risk of bad patient outcomes including postoperative stiffness.

There are several notable limitations of this study. The sample size is limited by the unique nature of these conversions. Conversions were performed by 4 different surgeons, which may slightly change instrumentation utilized. Furthermore, the measurement of ROM was performed by several practitioners and may have some variance and bias.

Conclusions

RA Conversion UKA to TKA is a new but equivalent technique to manual conversion. Our study did not show any statistically significant differences of primary RA or manual UKA to RA or manual TKA in terms of ROM at 1 year or need for augments with more complications in the manual to robotic group. Notably, primary UKA technique may impact the requirement for augments during conversion surgery.

Conflicts of interest

The authors declare there are no conflicts of interest.

For full disclosure statements refer to https://doi.org/10.1016/j.artd.2023.101269.

Table 5
Need for revision components or augments based on index technique of UKA.

Treatment	Primary manual (n = 23)	Primary robot (n = 28)	*P*-value	Revision manual (n = 22)	Revision robotic (n = 29)	*P*-value
Augments	12 (55%)	7 (25%)	.032	8 (36%)	11 (39%)	.83
Revision component	13 (59%)	17 (61%)	.91	14 (64%)	16 (57%)	.64

Author Contributions

Andrew Lachance contributed to writing – original draft. Alexander Edelstein contributed to conceptualization, writing – original draft, writing – review and editing. Jeffrey Lutton contributed to conceptualization, writing – original draft, writing – review and editing. Mason Stilwell contributed to conceptualization and supervision.

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