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Robotic-assisted unicompartmental knee arthroplasty has a greater early functional outcome when compared to manual total knee arthroplasty for isolated medial compartment arthritis

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Aims

The primary aim of the study was to compare the knee-specific functional outcome of robotic unicompartmental knee arthroplasty (rUKA) with manual total knee arthroplasty (mTKA) for the management of isolated medial compartment osteoarthritis. Secondary aims were to compare length of hospital stay, general health improvement, and satisfaction between rUKA and mTKA.

Methods

A powered (1:3 ratio) cohort study was performed. A total of 30 patients undergoing rUKA were propensity score matched to 90 patients undergoing mTKA for isolated medial compartment arthritis. Patients were matched for age, sex, body mass index (BMI), and preoperative function. The Oxford Knee Score (OKS) and EuroQol five-dimension questionnaire (EQ-5D) were collected preoperatively and six months postoperatively. The Forgotten Joint Score (FJS) and patient satisfaction were collected six months postoperatively. Length of hospital stay was also recorded.

Results

There were no significant differences in the preoperative demographics ($p \geqslant 0.150$) or function ($p \geqslant 0.230$) between the groups. The six-month OKS was significantly greater in the rUKA group when compared with the mTKA group (difference 7.7, $p < 0.001$). There was also a greater six-month postoperative EQ-5D (difference 0.148, $p = 0.002$) and FJS (difference 24.2, $p < 0.001$) for the rUKA when compared to the mTKA. No patient was dissatisfied in the rUKA group and five (6%) were dissatisfied in the mTKA, but this was not significant ($p = 0.210$). Length of stay was significantly ($p < 0.001$) shorter in the rUKA group (median two days, interquartile range (IQR) 1 to 3) compared to the mTKA (median four days, IQR 3 to 5).

Conclusion

Patients with isolated medial compartment arthritis had a greater knee-specific functional outcome and generic health with a shorter length of hospital stay after rUKA when compared to mTKA.

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Article focus

■ To compare the early (six-month) functional outcome, patient satisfaction, and length of hospital stay for patients undergoing robotic unicompartmental knee arthroplasty (rUKA) and manual total knee arthroplasty (mTKA).

■ Patients were matched for patient demographics, preoperative function, and pattern of osteoarthritis.

Key messages

■ Knee-specific functional outcome is both clinically and statistically significantly

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better for patients undergoing rUKA when compared to mTKA.
- Patients undergoing rUKA had a greater generic health score than those undergoing mTKA.
- rUKA is associated with a shorter length of hospital stay when compared to mTKA.

Strengths and limitations
- A powered prospective cohort study with < 10% loss to follow-up.
- Not randomized and short-term follow-up (six months).

Introduction
Unicompartmental knee arthroplasty (UKA) is an accepted management option for patients with end-stage isolated medial compartmental joint disease. The potential advantages of UKA are accelerated recovery, improved functional outcomes, and retention of anatomical knee kinematics when compared to total knee arthroplasty (TKA).[1-3] However, UKA is not universally employed by all surgeons as there is an associated higher revision rate when compared to TKA.[4] The 14th National Joint Register (NJR) report demonstrated the revision rate for the most common unicondylar knee arthroplasty, which was a mobile bearing prosthesis, to be 12% at ten years, which is four times greater than the revision rate for an unconstrained TKA (3%) in the same registry.[5] The higher revision rates of UKA are thought to be primarily due to component malpositioning, postoperative limb malalignment, and surgeon volume.[6-8]

Approximately 40% of components inserted during manual unicompartmental knee arthroplasty (mUKA) differ by more than 2° from the preoperative plan.[9] Robotic-assisted unicompartmental knee arthroplasty (rUKA) enables the surgeon to position the prosthesis up to four times more accurately when compared to mUKA.[10] It would also seem that implant positioning during rUKA is not influenced by surgeon volume.[11] A recent multicentre review of 432 fixed bearing rUKA demonstrated the six-year survivorship to be 97%,[12] which is supported by a recent systematic review.[13] This improved survival rate, when compared to mUKA, is thought to be due to improved accuracy and reliability of implant placement.[12,13] Implant position has not been directly related to functional outcome,[14] but an early comparative study of rUKA versus mUKA demonstrated better earlier outcomes for the robotic cohort.[15] Therefore, the accepted functional benefits of rUKA[16] and lower complication rates associated with UKA could potentially be enjoyed by the patient without the increased risk of early revision when compared to manual total knee arthroplasty (mTKA) for those with medial unicompartment disease.

The primary aim of this study was to compare the early knee-specific functional outcome of fixed bearing rUKA with mTKA for the management of isolated medial compartment osteoarthritis. Secondary aims were to compare length of hospital stay, general health improvement, and patient satisfaction between rUKA and mTKA.

Methods
Patients. Patients were recruited from two centres. Inclusion criteria included: isolated medial compartment osteoarthritis (complete radiological joint space loss); preservation joint space in other compartments of the knee joint; a varus deformity of < 10° which is correctible; flexion deformity < 15°; and a minimum of 90° of knee flexion. Exclusion criteria included the following: inflammatory arthritis; haemochromatosis; chondrocalcinosis; haemophilia; symptomatic knee instability or anterior cruciate ligament deficiency; multicompartment disease; previously failed correctional osteotomy or ipsilateral UKA; and immobility or other neurological conditions affecting musculoskeletal function. Radiographs were assessed for inclusion by one of four consultant orthopaedic surgeons (JTP, GM, PS for rUKA and NDC for mTKA). A consecutive series of 38 patients undergoing rUKA from one centre over a ten-month (May 2017 to February 2018) period had prospective data collected. At the other centre 213 patients underwent an mTKA for isolated medial compartment arthritis over a 12-month period, of which all met the preoperative criteria for UKA. Six-month outcome data were available for 30 rUKAs and 154 mTKAs.

Propensity score matching was used to derive a matched mTKA group for comparison of outcomes with the rUKA group. This technique is thought to offer a more accurate matching for case-control comparison and aims to match patients over a wider range of baseline characteristics.[17] First a 'propensity score' is calculated, which represents the chances of being in the rUKA group compared with the mTKA group. The score is derived from a multivariable binary logistic regression model based on several baseline characteristics. The variables selected for this study were age at operation, sex, body mass index (BMI), and preoperative functional scores. The rUKA group was the base group and the closest matching control from the TKA group was selected as the patient with a comparable propensity score. As a 1:3 ratio was used to power the study, the final cohort yielded 30 in the rUKA group and 90 in the mTKA group.

Surgical technique: rUKA. The MAKO (Stryker, Mahwah, New Jersey) robotic-arm assisted knee system was used in all cases. Tourniquet was not routinely used. During the study period three of the authors (JTP, GM, PS) performed all included rUKA operations. A preoperative segmented 3D CT scan of the patient's knee was constructed to aid surgical planning and dictate component positioning prior to surgery. The surgeon used the CT scan to help size and position the femoral and tibial components according to the patient's anatomy, with the aim to optimize bone coverage, restore joint line, minimize bone resection, and correct the mechanical axis.

A minimally-invasive medial parapatellar approach was made to the knee joint. Further stab incisions were made for the insertion of registration pins in the distal femur and proximal tibia onto which the arrays were mounted. Computer registration was performed by mapping pre-specified anatomical landmarks. Osteophytes were then excised. The varus deformity at the knee was corrected passively with manual valgus stress to tension the medial collateral ligament. The correction of the varus deformity was guided by the surgeon's feel of the soft-tissue envelope. The knee was taken through a range of movement (ROM) while applying the correction and data were collected by the computer regarding the medial joint space. This allowed a gap balancing graph to be created, which virtually plotted the joint gap through the ROM. This allowed the surgeon (JTP, GM, PS) to fine-tune the implant position, with the aim to balance the gap, and balance the soft-tissue envelope, through a full ROM. The computer virtually positions the implants and gap values of between 0 and 1.5 mm were deemed acceptable. A smooth transition from the trochlear to the anterior aspect of the femoral condyle was part of the plan for the femoral component. Once the implants were in place, central loading between femoral and tibial components was confirmed. A cemented Restoris MCK implant (Stryker, Kalamazoo, Michigan, USA) was used in all cases, which has a cobalt chrome femoral component and a titanium tibial component with a fixed, highly-crosslinked, polyethylene insert.

Surgical technique: mTKA. Tourniquet was routinely used. A midline medial parapatella approach was made with eversion of the patella. Intramedullary jig referencing was used for the femur, using the epicondylar axis and Whiteside's line[18] to set the rotation, and an extra-medullary jig was used for the tibia. The specified bone cuts were: 5° to 7° of valgus and neutral flexion/extension for the femoral component and zero varus/valgus with 3° of posterior slope for the tibial component. Soft tissue releases were then made as appropriate once the trial components were in place and osteophytes had been removed to achieve a balanced knee. The Triathlon (Stryker) TKA was used in all cases.

Postoperative rehabilitation. The postoperative rehabilitation regime was the same for both groups.

Outcomes. Preoperative and six-month functional outcomes were obtained prospectively for the rUKA cohort. The Oxford Knee Score (OKS),[19] Forgotten Joint Score (FJS),[20] EuroQol five-dimension questionnaire (EQ-5D) score,[21] level of pain, and patient satisfaction with their knee were assessed. The OKS, EQ-5D, and level of pain were assessed pre- and postoperatively. FJS and level of patient satisfaction were only assessed six months postoperatively.

The OKS is a knee-specific score and was used as the primary outcome measure. This score consists of 12 questions assessed on a Likert scale with values from 0 to 4. A summative score is then calculated where 48 is the best possible score (least symptomatic) and 0 is the worst possible score (most symptomatic).[22] The FJS assesses joint awareness during the activities of daily living (for example, climbing stairs, walking for more than 15 minutes, in bed at night, etc.).[20] It consists of 12 questions assessed using a five-point Likert response format. Item scores are summed and linearly transformed to a 0 to 100 scale, a high value reflecting the ability of the patient to forget about the affected/replaced joint during the activities of daily living. The EQ-5D was used, which measures five domains (mobility, self-care, usual activities, pain/discomfort, and anxiety/depression) according to three levels (3L) of severity (none, some/moderate, or unable/extreme).[21] An individual patient's health state can be reported based on the five-digit code for each domain, of which there are 243 possible health states. A visual analogue scale (VAS) of 0 to 100 was used to assess pain.

Patient satisfaction was assessed by asking the question "How satisfied are you with your operated knee?" The response was recorded using a five-point Likert scale: very satisfied; satisfied; neither; dissatisfied; and very dissatisfied. Patients who recorded 'very dissatisfied' or 'dissatisfied' were classified as 'dissatisfied'. This has been used previously to assess patient satisfaction after TKA.[23] Patients were also asked: "Would you have this operation again if it was required on another joint?". The response was recorded using a five-point Likert scale: extremely likely; likely; neither; unlikely; and extremely unlikely. A sixth option of "don't know" was also included.

Statistical analysis. Data analysis was performed using Statistical Package for Social Sciences version 17.0 (SPSS, Chicago, Illinois, USA). Parametric and non-parametric tests were used as appropriate to assess continuous variables for significant differences between groups. A Mann-Whitney U test and Student's t-test, unpaired and paired, were used to compare linear variables between groups. Dichotomous variables were assessed using Fisher's exact test. A p-value of < 0.05 was defined as significant.

A power calculation was performed using the OKS (primary outcome measure), which has a defined minimal clinically important difference of five points and an SD of nine points.[24] A 1:3 ratio was used as there were cost implications of 1:1 comparison. This determined that a minimum of 28 patients in the rUKA group and 82 patients in the mTKA group would achieve a power of 0.80 using one-tailed analysis (assumed better outcome in rUKA) and an alpha value of 0.05.

Results

After propensity score matching, the two groups were similar, with no statistically significant differences in patient demographics or preoperative functional scores (Table I).

Table I. Patient demographics and preoperative functional scores according to group

Descriptive	rUKA (n = 30)	mTKA (n = 90)	Difference (95% CI)	p-value
Sex, n (%)			0.78* (0.28 to 2.13)	0.804†
Male	24 (9.3)	68 (14.8)	N/A	N/A
Female	6 (90.7)	22 (85.2)	N/A	N/A
Mean age, yrs (SD)	65.9 (12.0)	67.8 (8.3)	1.6 (–0.9 to 4.1)	0.152‡
Mean BMI, kg/m² (SD)	30.5 (8.4)	29.7 (4.9)	0.8 (–1.8 to 3.3)	0.565‡
Mean PROM (SD)				
Preoperative OKS	27.6 (5.4)	24.9 (7.5)	2.7 (–1.1 to 6.5)	0.310‡
Preoperative EQ-5D	0.561 (0.201)	0.521 (0.241)	0.040 (–0.018 to 0.098)	0.233‡
Preoperative pain VAS	58.6 (19.9)	55.7 (22.3)	2.9 (–7.6 to 13.4)	0.591‡

*Odds ratio
†Fisher's exact test.
‡Unpaired t-test.
BMI, body mass index; CI, confidence interval; EQ-5D, EuroQol five-dimension questionnaire; mTKA, manual total knee arthroplasty; N/A, not applicable; OKS, Oxford Knee Score; PROM, patient reported outcome measure; rUKA, robotic unicompartmental knee arthroplasty; VAS, visual analogue scale.

Table II. Six-month postoperative outcome measures and the difference between groups

Mean PROM (SD)	rUKA	mTKA	Difference (95% CI)	p-value*
Postoperative OKS	44.2 (4.4)	36.5 (9.4)	7.7 (4.2 to 11.3)	< 0.001
Postoperative FJS	77.1 (25.9)	52.9 (32.6)	24.2 (11.2 to 37.2)	< 0.001
Postoperative EQ-5D	0.913 (0.126)	0.764 (0.248)	0.148 (0.054 to 0.241)	0.002
Postoperative pain VAS	93.6 (12.3)	76.4 (24.8)	20.5 (9.9 to 31.0)	< 0.001

*Unpaired t-test.
CI, confidence interval; EQ-5D, EuroQol five-dimension questionnaire; FJS, Forgotten Joint Score; mTKA, manual total knee arthroplasty; OKS, Oxford Knee Score; PROM, patient-reported outcome measure; rUKA, robotic unicompartmental knee arthroplasty; VAS, visual analogue scale.

Functional Outcome. The rUKA group had a significantly greater six-month OKS of nearly eight points (Table II). There was a five point (95% confidence interval (CI) 1.9 to 8.1; p < 0.001, unpaired t-test) greater improvement in the OKS in the rUKA group compared to the mTKA, which was greater than the minimal clinically important difference (MCID).[25] In addition, there was a smaller SD observed for the rUKA group (4.4) compared to the mTKA group (9.4), which suggests a tighter and more reliable distribution of outcome scores. The six-month FJS, also a joint-specific score, was significantly greater for the rUKA group compared to the mTKA group and was greater than the minimally important difference of 14 points (Table II).[26] The six-month generic health EQ-5D score and pain VAS were significantly greater in the rUKA group (Table II). All outcome scores were greater at six months in the rUKA group when compared to the mTKA group (Figure 1).

Satisfaction. Six patients from the mTKA group did not answer the question regarding satisfaction with their knee. No patient was dissatisfied with their rUKA and five patients were dissatisfied with their mTKA, but this did not achieve statistical significance (Table III). Three patients in the rUKA group replied with 'don't know' and two in the mTKA group did not answer the question as to whether they would have surgery again. Other than the two patients in the rUKA group that declared they 'don't know', all would undergo surgery again, whereas only 91% of the mTKA group would undergo surgery again (Table III).

Length of hospital stay. Length of stay was significantly (p < 0.001, Mann-Whitney U test) shorter in the rUKA group (median two days, interquartile range (IQR) 1 to 3 days) compared to the mTKA (median four days, IQR 3 to 5 days).

Discussion

This study has demonstrated a statistically and clinically significant greater early knee-specific functional outcome for patients undergoing rUKA when compared to mTKA for isolated medial compartment arthritis. In addition, those receiving rUKA also had a greater general health score and had subjectively less knee pain at six months compared with the mTKA group. There was a trend towards a greater rate of patient satisfaction and willingness to undergo surgery again in the rUKA group, but this did not reach statistical significance. The length of stay for the rUKA group was half of that observed in the mTKA group.

The major limitation of this study was the non-randomization of the surgical intervention (group) between two different hospitals. The three surgeons (JTP, GM, PS) work between the two hospitals but rUKA is not available in one, and patients in that institution are offered an mTKA or an mUKA. There were only 12 mUKAs performed in the non-rUKA centre during the study period. The authors felt that this low rate of mUKA is reflected in the UK, with only 8% of primary knee arthroplasties being a UKA[3] and is as low as 3% in some regions.[27] This low rate of uptake for mUKA
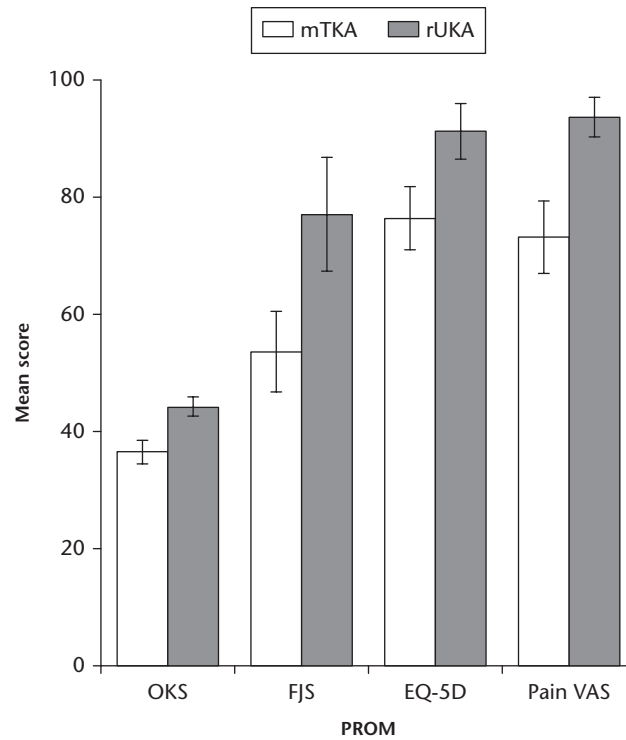
Fig. 1

Six-month postoperative patient-reported outcome measures (PROMs) for the robotic unicompartmental knee arthroplasty (rUKA, grey bars) and manual total knee arthroplasty (mTKA, white bars) groups. Error bars represent 95% confidence intervals. EQ-5D, EuroQol five-dimension questionnaire; FJS, Forgotten Joint Score; OKS, Oxford Knee Score; VAS, visual analogue scale.

Table III. Six-month postoperative satisfaction according to group

Question	rUKA, n (%)	mTKA, n (%)	p-value*
Are you satisfied with your knee?			0.210
Yes	30 (100)	79 (94.0)	
No	0 (0)	5 (6.0)	
Would you have this operation again?			0.109
Yes	27† (100)	80 (91.0)	
No	0 (0)	8 (9.0)	

*One-tailed Fisher's exact test.
†Three patients responded with 'don't know' to this question and were excluded.
mTKA, manual total knee arthroplasty; rUKA, robotic unicompartmental knee arthroplasty.

did, however, allow the comparison of the different interventions between the two groups that had the same pattern of joint disease (medial compartment), which would have not been possible if rUKA was available in both centres. Previous studies comparing the outcome of UKA with TKA often match for patient variables and preoperative score but not for disease pattern, with some patients in the TKA group having bi- and tri-compartmental disease.[28,29] The length of follow-up is short, reporting only six-month data, and this may change with longer follow-up and should be assessed in future studies. However, the majority of the improvement in the

OKS occurs in the first six months, with only a one to two-point further increase by 12 months.[30] Six-month data are collected by the NJR. Comparative studies of UKA versus TKA using this data found a 1.5-point difference in the postoperative OKS between the groups,[28,31] which is not clinically significant as is it is less than the MCID.[24] In contrast, the current study at this same time-point found a statistically and clinically (being more than the MCID) significantly greater OKS in the rUKA group and supports a better 'early' functional outcome, but whether this will be observed into the mid-to-longer term remains unknown. The 3:1 group ratio could also be raised as a limitation of the study. This ratio was chosen because of the availability of data from the two centres included. The hospital used to select the matched mTKA cohort was a large-volume arthroplasty centre whereas the hospital performing rUKA was a smaller-volume centre. However, one advantage of the larger number of mTKAs being available with six-month outcomes was the ability to propensity score match to the smaller defined rUKA group, which enabled a powered comparative study to be conducted. The propensity score matching did not include patient comorbidities, which is a limitation, but did include the EQ-5D, which is a marker of generic physical and mental health.[32] Also, tourniquet was used in the mTKA but not routinely for the rUKA. While this has been shown to influence early

functional outcome, these differences are not observed six months postoperatively.[33]

The early functional outcome after mUKA is recognized to be better than that observed after TKA,[28] which supports the results of the current study when comparing rUKA to mTKA. The postoperative OKS in the rUKA group of 44 was eight points greater than the mTKA group with a five-point greater improvement, relative to their preoperative OKS, which is the minimal clinically important difference.[24] This is greater than the two-point difference demonstrated between mUKA and mTKA using NJR data.[28] The reason for the greater difference using rUKA is not clear and may relate to more accurate implant positioning and soft-tissue balancing when compared to mUKA.[10] However, the early functional outcome between mUKA and rUKA has not been shown to be different.[34] The high postoperative OKS is supported by a high FJS in the rUKA group; 77% of rUKA patients had an FJS, which is similar to the 73% reported by Blyth et al[35] in their cohort of 64 patients one year after rUKA. The reported FJS after mTKA varies from 42[36] to 59,[37] whereas the FJS after rUKA seems to be more in keeping with total hip arthroplasty where the score is reported to be between 48[36] and 76.[38] However, these functional results should be confirmed in future prospective comparative studies.

Previous studies have shown that mUKA is more cost-effective than mTKA.[39,40] While there is a higher revision rate associated with mUKA, the benefit of shorter hospital length of stay, lower rates of complications, hospital/implant costs, and a greater number of QALYs gained make it more cost-effective than mTKA.[39,40] However, if there is an improved survivorship associated with the rUKA, which early data suggest,[12] this may negate the increased costs of robotic surgery.[41] A cost-effective analysis assessing rUKA with mUKA found that the increased implant survival, and secondary QALYs gained, resulted in rUKA being more cost-effective provided the annual caseload was greater than 94.[42] In addition, the shorter length of stay observed in the current study (two days) should also be taken into account as a cost saving for the centre relative to mTKA. A recent cost economic study [41] using published outcome data demonstrated rUKA to be a cost-effective alternative to both mUKA and mTKA when accounting for the increased costs of robotic surgery against the potential benefits, one of which was improved functional outcome and is supported by the results of the current study.

The importance of implant positioning is well recognized in TKA, where small changes in alignment can result in substantial changes in the forces across the prosthesis.[43] Furthermore, a kinematically aligned TKA is more likely to replicate the normal kinematics of the knee joint.[44] Robotic-assisted surgery will help the surgeon position the implant with more accuracy, but the optimal position is not clear.[45] Small changes in the orientation of a UKA have been shown to considerably increase the cortical stain around the tibial component, which could lead to pain and subsidence.[46] Robotic assistance can help with the alignment, but implant design should also be considered as a potential factor influencing outcome. The all polyethylene tibial component as part of UKA has been shown to cause increased cortical strain relative to a metal backed component and is more sensitive to coronal plane malalignment,[47,48] and has been associated with an increased early revision rate.[13] Furthermore, patient-specific UKA is biomechanically superior to standard off-the-shelf components.[49] The optimal design of the UKA prothesis is not clear, where increasing conformity decreases polyethylene wear but also limits the kinematics of the knee joint.[50] In the current study a cemented prosthesis was used, but the robot may be able to aid the surgeon with an optimal interference fit that may also support the use of an uncemented tibial component in future studies.[51]

Patients with isolated medial compartment arthritis had a greater knee-specific functional outcome and generic health with a shorter length of hospital stay after rUKA when compared to mTKA. Whether the early functional benefits of rUKA over mTKA are observed into the mid-to-longer term needs to be assessed.

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