Evaluation of changes in fixed flexion deformity following medial unicompartmental knee arthroplasty

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Aims

While residual fixed flexion deformity (FFD) in unicompartmental knee arthroplasty (UKA) has been associated with worse functional outcomes, limited evidence exists regarding FFD changes. The objective of this study was to quantify FFD changes in patients with medial unicompartmental knee arthritis undergoing UKA, and investigate any correlation with clinical outcomes.

Methods

This study included 136 patients undergoing robotic arm-assisted medial UKA between January 2018 and December 2022. The study included 75 males (55.1%) and 61 (44.9%) females, with a mean age of 67.1 years (45 to 90). Patients were divided into three study groups based on the degree of preoperative FFD: ≤ 5°, 5° to ≤ 10°, and > 10°. Intraoperative optical motion capture technology was used to assess pre- and postoperative FFD. Clinical FFD was measured pre- and postoperatively at six weeks and one year following surgery. Preoperative and one-year postoperative Oxford Knee Scores (OKS) were collected.

Results

Overall, the median preoperative navigated (NAV) FFD measured 6.0° (IQR 3.1 to 8), while the median postoperative NAV FFD was 3.0° (IQR 1° to 4.4°), representing a mean correction of 49.2%. The median preoperative clinical FFD was 5° (IQR 0° to 9.75°) for the entire cohort, which decreased to 3.0° (IQR 0° to 5°) and 2° (IQR 0° to 3°) at six weeks and one year postoperatively, respectively. A statistically significant improvement in PROMs compared with baseline was evident in all groups ($p < 0.001$). Regression analyses showed that participants who experienced a larger FFD correction, showed greater improvement in PROMs ($\beta = 0.609$, $p = 0.049$; 95% CI 0.002 to 1.216).

Conclusion

This study found that UKA was associated with an approximately 50% improvement in preoperative FFD across all three examined groups. Participants with greater correction of FFD also demonstrated larger OKS gains. These findings could prove a useful augment to clinical decision-making regarding candidacy for UKA and anticipated improvements in FFD.

Take home message

- Medial unicompartmental knee arthroplasty can be a successful treatment option in patients with medial compartment osteoarthritis and with flexion contractures up to 15°.
- Change in fixed flexion deformity correlated with preoeprative flexion contracture and also improvements in patient-reported outcome measures.

Introduction

The demand for knee arthroplasty is increasing as a result of an ageing and more active population with greater functional demands.[1] For a proportion of these

patients, the disease is isolated to a single compartment of the knee joint, and unicompartmental knee arthroplasty (UKA) is a successful alternative to total knee arthroplasty (TKA).[1,2] Advocates of UKA emphasize its capacity to better preserve the knee ligamentous structures, which allows for more dynamic proprioception and postural control compared to TKA.[3] Further benefits of UKA compared to TKA include reduced perioperative morbidity and mortality, quicker recovery, shorter hospital stays, reduced infection rates, and superior patient satisfaction.[4-7]

Initially quoted indications for medial UKA by Kozinn and Scott[8] encompassed single compartment disease, varus/valgus deformity less than 10°, intact cruciate ligaments, knee flexion greater than 90°, and preoperative fixed flexion deformity (FFD) < 5°. Historically, this set of criteria was regarded as the benchmark for medial UKA. Nevertheless, over time, these criteria have been subjected to scrutiny. Updated criteria have been suggested, which include grade IV anteromedial arthritis or > 95% loss of medial knee joint space, with < 25% loss of lateral compartment joint space.[9] Significantly, these updated criteria no longer impose limitations related to age, weight, activity levels, degeneration of the medial facet of the patella, or cartilage damage in the medial region of the lateral compartment.[9] Also, studies indicate that optimal outcomes are achieved when these procedures are undertaken by high-volume UKA surgeons.[10,11] Studies analyzing candidacy for UKA suggest that this technique may be underutilized, and up to almost 48% of those who undergo TKA would in fact be suitable for UKA.[12-15] The eligibility criteria for UKA remain controversial, particularly regarding the presence of a flexion contracture. This is due to the established association between residual FFD following UKA and suboptimal functional outcomes.[16,17] The currently employed contraindication of a flexion contracture > 10° results in the exclusion of a significant proportion of patients with more advanced knee arthritis. However, there may be a proportion with single compartment disease and FFDs that are surgically correctable during UKA.

Robotic arm assistance in UKA has grown in popularity as a technique for improving the accuracy of component positioning and reducing errors in limb alignment.[18-24] The procedure also uses optical motion capture technology, allowing assessment of real-time changes in intraoperative knee kinematics. It has been shown that it exhibits little to no learning curve to achieve accurate implant positioning.[25] Furthermore, it has been associated with superior radiological outcomes compared with the conventional technique.[26,27] Hence, it could conceptually provide an avenue for low-volume UKA surgeons to achieve high levels of accuracy and reproducibility in component positioning and limb alignment.[28]

The primary objective of this study was to quantify FFD changes in patients undergoing medial UKA, utilizing a robotic system's optical motion capture technology. Furthermore, we aimed to ascertain whether there was any correlation with patient-reported or clinical outcomes. The hypothesis was that CT-based robotic arm-assisted UKA would lead to improvements in the FFD in patients with mild disease (< 10° flexion contractures), but no changes in FFD in patients with more advanced knee disease (> 10° flexion contractures). The secondary objective was to ascertain whether there was any correlation between preoperative FFD and early patient-reported outcomes.

Methods

This prospective cohort study included 136 patients with medial unicompartmental knee arthritis, undergoing robotic arm-assisted UKA (RO UKA) between January 2018 and December 2022. Inclusion criteria comprised osteoarthritis (OA) or osteonecrosis limited to the medial compartment; preservation of the other compartments; passively correctible varus deformity of less than 10°; fixed flexion deformity less than 15°; maximum knee flexion greater than 90°. Exclusion criteria comprised the following: inflammatory arthritis, symptomatic knee instability or anterior cruciate ligament deficiency; multi-compartment disease; previously failed correctional osteotomy or ipsilateral UKA; previous fracture involving the knee joint; immobility; or any neurological condition which affects the musculoskeletal function. Hospital review board approval was gained prior to commencement of this study. All study patients provided consent for participation.

The following outcomes were recorded in all study patients: age; sex; clinical FFD, as measured using a goniometer in the outpatient clinic preoperatively and postoperatively at six weeks and one year after surgery; preoperative and postoperative navigated FFD (NAV FFD), as measured using the optical motion capture technology prior to the surgical incision and after the final prosthesis implantation, respectively; and the Oxford Knee Score (OKS)[29,30] at one year after surgery. The use of a goniometer has been shown to be a useful and reproducible method of measuring sagittal knee deformity.[31,32] Patients were divided into three groups based on the level of their preoperative FFD: ≤ 5°, 5° to ≤ 10°, and > 10°.

Power analysis and sample size calculation

In order to determine the sample size necessary for our study, we conducted a priori power analysis. In a study evaluating changes in FFD following UKA, the reported mean change postoperatively was 9.8 (SD 4.5).[33] Given SD of 4.5 and a desired power of 80%, our study would need a sample of 126 pairs to detect a mean difference of 1°, with a one-sided test at a 5% significance level. To account for potential data loss or unforeseen circumstances that could impact our analysis, our study encompassed a total of 136 paired observations.

Surgical technique

All surgical procedures were undertaken using the Mako robotic-arm UKA platform (Stryker, USA). Preoperative CT scans were used to assess osseous anatomy (including careful delineation of any osteophytes) and overall limb alignment. Patient-specific computer-aided design models were used to plan optimal implant positioning. The medial parapatellar approach was used in cases. Registration pins for the fixed arrays were inserted through the original surgical incision, negating the need for separate stab incisions. Medial access was gained to excise accessible medial osteophytes. A formal corrective medial release was not performed. Excision of intercondylar notch osteophyte was performed, facilitating a distal femoral cut parallel to the femoral condyle. Bony cuts were then executed and prior to trial implants any posterior

Table I. Patients' characteristics and fixed flexion deformity pre- and postoperatively for the entire cohort.

Variable	Patients undergoing medial UKA (n = 136)
Mean age, yrs (range)	67.1 (45 to 90)
Sex, n (%)	
Male	75 (55.1)
Female	61 (44.9)
Median preoperative clinical FFD, ° (IQR)	5.0 (0 to 9.75)
Median preoperative FFD on navigation, ° (IQR)	6 (3.1 to 8)
Median postoperative FFD on navigation, ° (IQR)	3 (1 to 4.4)
Median Delta FFD (navigation), ° (IQR)	3 (1.6 to 4)
Mean change, % (range)	47 (36 to 67)
Median clinical FFD at 6 weeks, ° (IQR)	3 (0 to 5)
Change in FFD at 6 weeks, ° (IQR)	3 (1 to 5)
Median clinical FFD at 1 year, ° (IQR)	2 (0 to 3)
Median change in FFD at 1 year, ° (IQR)	5 (3 to 6.5)

FFD, fixed flexion deformity.

Table II. Patients' characteristics and fixed flexion deformity (FFD) pre- postoperatively between the FFD groups.

Variable	FFD ≤ 5° (n = 59)	FFD 5° to ≤ 10° (n = 58)	FFD > 10° (n = 19)	p-value
Mean age, yrs (range)	66.4 (45 to 90)	67.2 (45 to 86)	67.3 (50 to 85)	0.785*
Sex, n (%)				
Male	28 (47.5)	37 (63.8)	10 (52.6)	0.201†
Female	31 (52.5)	21 (36.2)	9 (47.4)	
Median preoperative clinical FFD, ° (IQR)	5 (0 to 5)	6 (4.5 to 10)	10 (10 to 12)	< 0.001‡
Median preoperative FFD on navigation, ° (IQR)	3 (1 to 4)	7 (6 to 8)	11.5 (10.5 to 12.5)	< 0.001‡
Median postoperative FFD on navigation, ° (IQR)	1 (0 to 2)	4.0 (3 to 4)	7.0 (6 to 7)	< 0.001‡
Median change in FFD navigation, ° (QR)	2 (0.5 to 3)	3.5 (2.5 to 4.5)	4.5 (4 to 5.5)	< 0.001‡
Change, %	60.7	48.6	40.1	
Median clinical FFD at 6 weeks, ° (IQR)	0 (0 to 3)	3.5 (0 to 5)	6 (5 to 7)	< 0.001‡
Median change in FFD at 6 weeks, ° (IQR)	2 (0.3 to 5)	3 (1 to 5)	5 (4 to 5)	0.001‡
Median clinical FFD at 1 year, ° (IQR)	0 (0 to 2)	2 (0 to 3)	5 (3 to 5)	< 0.001‡
Median change in FFD at 1 year, ° (IQR)	2 (0 to 5)	4 (1.75 to 6)	7 (5 to 8)	< 0.001‡

*One-way analysis of variance (ANOVA).
†Pearson chi-squared test.
‡Kruskal-Wallis test.
FFD, fixed flexion deformity.

femoral condyle osteophytes were excised using an osteotome with the knee held in flexion. The posteromedial capsule was subsequently released when indicated using a Bristow elevator with the knee in approximately 90° of flexion to enhance the correction of any pre-existing FFD. Trial components were then inserted, and stability, range of motion (ROM), and FFD were recorded. Intraoperative poses were captured from extension to 120° of flexion. Gap-balancing graphs were formulated whereby positive values reflected ligamentous laxity and negative values represented ligamentous tightness. Implant sizes and positions were adjusted to secure equal laxity throughout the knee's ROM, with positive and negative gap values within 0 mm to 1.5 mm of neutral through the arc of flexion. The documented preoperative NAV FFD was recorded prior to bony cuts being made with the knee in extension and the postoperative NAV FFD measurement was recorded after implantation of the final prosthesis. No manual corrective forces were applied during assessment of these measurements.

Statistical analysis

Categorical data are presented using the absolute number and percentages, while continuous variables used the mean and SD. To ascertain whether the assumption of normality was violated, Kolmogorov-Smirnov and Shapiro-Wilk tests were performed. A one-way analysis of variance (ANOVA) was used for continuous variables. The skewness, kurtosis, and boxplots were also evaluated. Linear regression models were employed to investigate the impact of different variables on achieving a larger improvement in OKS or FFD. SPSS statistics software for Mac v. 29 (IBM, USA) was used for all analyses. Statistical significance was set at a two-tailed p-value < 0.05.

Results

Changes in FFD

Overall, 136 patients were included in our study with a median preoperative NAV FFD 6.0° (IQR 3.1° to 8.0°). There were 75 (55.1%) males and 61 (44.9%) females, with a mean age of 67.1 years (45 to 90). Median postoperative NAV FFD was 3.0° (IQR 1.0° to 4.4°), representing a mean deformity correction of 49.2% for the entire cohort. We noted a reduction of the median clinical FFD at the six-week and one-year postoperative timepoints of 3.0° (IQR 0° to 5.0°) and 2.0° (IQR 0° to 3.0°), respectively, compared to the median preoperative clinical FFD of 5.0° (IQR 0° to 9.75°) (Table I).

When divided into preoperative NAV FFD groups, the ≤ 5° group consisted of 59 patients, the 5° to ≤ 10° group of 58 patients, and the > 10° group of 19 patients (Table II). Age and sex were comparable among the groups (66.4 vs 67.2 vs 67.3 years). The median respective preoperative NAV FFD was 3° (IQR 1 to 4), 7° (IQR 6° to 8°), and 11.5° (IQR 10.5° to 12.5°). The median postoperative recorded NAV FFD amongst participants in the three groups was 1° (IQR 0° to 2°), 4° (IQR 3° to 4°), and 7° (IQR 6° to 7°), which accounted for a mean FFD correction of 60.7%, 48.6%, and 40.1% respectively. Changes in NAV FFD and clinical FFD at six weeks and one year reached statistical significance in all groups.

Table III. Baseline and one-year Oxford Knee Scores between the fixed flexion deformity groups.

Variable	FFD ≤ 5° (n = 59)	FFD 5° to ≤ 10° (n = 58)	FFD > 10° (n = 19)	p-value*
Mean preoperative OKS (SD)	23.2 (7.9)	21 (7.5)	22.8 (8)	0.343
Mean OKS at 1 year (SD)	43.3 (3.6)	44.8 (3.2)	45.5 (3)	0.079

*One-way analysis of variance (ANOVA).
OKS, Oxford Knee Score.

Table IV. Linear regression models with respect to change in Oxford Knee Score.

Variable	β	95% CI	p-value
Age, yrs	-0.103	-0.23 to 0.031	0.131
Sex	0.009	-2.5 to 2.52	0.994
Preoperative FFD (navigation)	0.018	-0.46 to 0.50	0.941
Change in FFD (navigation)	0.588	-0.23 to 1.40	0.154

FFD, fixed flexion deformity.

Patient-reported outcome measures

A statistically significant improvement in patient-reported outcome measures (PROMs) compared with baseline was evident in all groups. Improvements in OKS at one year postoperatively were comparable among the groups (Table III).

Impact of FFD on PROMs improvement

Linear regression analysis was used to compare the change OKS scores after adjusting for age and sex. Results showed that the FFD 5° to ≤ 10° group showed a greater improvement in PROMs compared to the FFD ≤ 5° group, albeit not clinically significant; the FFD < 5° to ≤ 10° group (β = 2.68, p = 0.046; 95% CI -0.045 to 5.32); and the FFD > 10° group (β = 1.41, p = 0.452; 95% CI -2.31 to 5.14).

To investigate the impact of the preoperative FFD on improvements in OKS, after adjusting for age and sex, a linear regression analysis was performed. Results showed no statistical significance (β = 0.179, p = 0.239; 95% CI -0.121 to 0.479). When examining the impact of the δ FFD on OKS improvement after adjusting for age and sex, we found that participants who experienced a larger FFD correction showed greater improvement in PROMs (β = 0.609, p = 0.049; 95% CI 0.002 to 1.216).

Finally, after adjusting for age and sex, the preoperative FFD was not associated with the magnitude of the percentage change in FFD (β = -0.010, p = 0.646; 95% CI -0.054 to 0.034).

A multivariate linear regression model was then constructed to identify whether any variables were associated with a larger improvement in OKS (change in OKS). Variables were entered in the model based on univariate analyses and clinical significance. In detail, we entered the following variables; age, sex, preoperative FFD (based on navigation), and change in FFD (based on navigation). The model explained 7.8% of the variation (R squared 0.078) and the β values obtained for the different variables entered can be found in Table IV.

Discussion

This study hypothesized that UKA would result in an improvement of mild FFD of < 10°, but not more advanced knee disease with FFD exceeding 10°. This hypothesis was partially validated, as postoperative improvements in FFDs were observed across all patient groups. Notably, the preoperative FFD improved by approximately 50% across all three study groups. Importantly, improvements in the OKS were recorded across all three treatment groups at one-year follow-up. To our knowledge, this is the first study to quantify changes in FFD following UKA using optical motion capture technology.

Studies in the literature have shown that UKA is a successful procedure with lower levels of complications, morbidity, and mortality, as well as greater functional outcomes and cost-effectiveness when compared to TKA.[4–7,34–36] Moreover, several studies have confirmed excellent survival of UKA.[37–40] These encouraging findings support the use of UKA whenever feasible. The primary indication for medial UKA is severe anteromedial OA.[15,41] While consensus exists regarding the limited contraindications for UKA, namely tricompartmental arthritis, inflammatory arthritis, and severe lateral patella facet degeneration,[41–43] there remains no broad agreement concerning acceptable levels of preoperative FFD for UKA candidacy. Our study found that the combination of posterior femoral condyle osteophyte excision and posteromedial capsular release when indicated resulted in approximately 50% reduction of the FFD. Furthermore, the use of robotic arm assistance could have conferred further benefits by enabling more accurate bone cuts, adjustment of slope, and individualized implant positioning, hence allowing for accurate restoration of the intra-articular deformity.[44] Optical motion capture technology also allowed for repeated assessments of the FFD correction intraoperatively.

While extensive literature exists on the effect of postoperative contractures on functional outcomes following UKA,[16,17,45] there is a relative paucity of studies addressing the influence of preoperative contractures on postoperative outcomes. Goh et al[46] conducted a study whereby 87 patients with a flexion contracture of > 15° who underwent UKA were matched with 87 patients without any contractures undergoing UKA. The authors reported that patients with severe preoperative contractures achieved a reduced ROM in the postoperative period. Notwithstanding this, satisfaction rates, functional outcomes, and mid-term survival were comparable between the groups. Additionally, only 9% of the patients with a preoperative FFD of > 15° did not experience a reduction of FFD at two years postoperatively.[46] These findings align with our results, showcasing that partial correction of flexion can be achieved through comprehensive osteophyte excision and posteromedial capsule release.

We noted that the maximum correction in clinical FFD was achieved at one year follow-up. In patients with < 5°, 5° to 10°, and > 10° of preoperative flexion contractures, the median clinical FFD at one year was 0° (IQR 0° to 2°), 2° (IQR 0° to 3°), and 5° (IQR 3° to 5°), respectively. A possible explanation could involve compliance and engagement with physiotherapy exercises and appointments. Moreover, Purcell et al[33] conducted a matched study comparing 53 patients with a mean FFD of 13.8° who underwent UKA with 53 patients

with a mean FFD of 14.1° who underwent TKA. The authors noted greater Knee Society Score (KSS) functional outcomes and comparable KSS objective scores in the UKA group compared to the TKA group. These results further support the potential suitability of UKA in patients with FFD > 10°. In our study, when evaluating the predictive value of several variables on PROMs improvement, we found no correlation between preoperative flexion contracture and change in OKS. We also observed that there was no effect of preoperative NAV FFD on the percentage of the FFD correction. However, when adjusting for age and sex, patients with greater change in NAV FFD showed greater improvements in OKS ($p = 0.049$).

Our study findings suggest that UKA could represent a successful treatment modality in patients with preoperative FFD of up to 15°. Furthermore, the condition of the patellofemoral joint (PFJ) is not an absolute contraindication provided there is not severe damage to the lateral PFJ.[47–49] Konan and Haddad[50] reviewed 100 consecutive medial Oxford UKAs with a minimum follow-up of eight years and correlated their functional outcomes to documented intraoperative patellofemoral chondral loss and topographical location. They reported that topographical location and severity of chondral loss notably influenced function, with severe central and lateral PFJ being related to lower function and satisfaction. Nevertheless, patients with medial patellofemoral chondral lesions exhibited similar outcomes to patients with no chondral loss.[50] In our study, a combination of osteophyte excision, posterior capsule release, and adjustments to component positioning with RO UKA resulted in considerable improvements in FFDs across all treatment groups.

Some limitations exist that warrant acknowledgment. First, our study included patients with outcomes recorded only to one-year follow-up. It is possible that patients with more advanced preoperative FFDs will have increased risk of recurrence with longer follow-up. Second, the study is limited to patients with medial compartment disease undergoing UKA. Furthermore, it should be acknowledged that employing a goniometer for clinical measurement of FFD may result in reduced accuracy, especially when differences are within a few degrees. Lastly, all RO UKAs were performed by high-volume, fellowship-trained arthroplasty surgeons who are past the learning curve, potentially affecting the generalizability of our findings.

In conclusion, this study found that robotic arm-assisted medial UKA was associated with an approximately 50% improvement in preoperative FFD. Importantly, the change in FFD was related to the degree of preoperative FFD, and improvements in the OKS were observed across all three treatment groups. These findings could prove a useful augment to clinical decision-making regarding candidacy for UKA and anticipated improvements in FFD. To our knowledge, this is the first study to use optical motion capture technology to quantify changes in FFD during robotic arm-assisted UKA. Further studies are required to establish the maximum FFD that can be corrected during UKA and the long-term outcomes of patients with FFDs above the current threshold of < 10° flexion contracture.

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Data sharing

The datasets generated and analyzed in the current study are not publicly available due to data protection regulations. Access to data is limited to the researchers who have obtained permission for data processing. Further inquiries can be made to the corresponding author.

Ethical review statement

University College Hospital review board approval was gained prior to commencement of this study.