Does component placement affect short-term clinical outcome in robotic-arm assisted unicompartmental knee arthroplasty?

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Aims
The purpose of this multicentre observational study was to investigate the association between intraoperative component positioning and soft-tissue balancing on short-term clinical outcomes in patients undergoing robotic-arm assisted unicompartmental knee arthroplasty (UKA).

Patients and Methods
Between 2013 and 2016, 363 patients (395 knees) underwent robotic-arm assisted UKAs at two centres. Pre- and postoperatively, patients were administered Knee Injury and Osteoarthritis Score (KOOS) and Forgotten Joint Score-12 (FJS-12). Results were stratified as "good" and "bad" if KOOS/FJS-12 were more than or equal to 80. Intraoperative, post-implantation robotic data relative to CT-based components placement were collected and classified. Postoperative complications were recorded.

Results
Following exclusions and losses to follow-up, 334 medial robotic-arm assisted UKAs were assessed at a mean follow-up of 30.0 months (8.0 to 54.9). None of the measured parameters were associated with overall KOOS outcome. Correlations were described between specific KOOS subscales and intraoperative, post-implantation robotic data, and between FJS-12 and femoral component sagittal alignment. Three UKAs were revised, resulting in 99.0% survival at two years (95% confidence interval (CI) 97.9 to 100.0).

Conclusion
Although little correlation was found between intraoperative robotic data and overall clinical outcome, surgeons should consider information regarding 3D component placement and soft-tissue balancing to improve patient satisfaction. Reproducible and precise placement of components has been confirmed as essential for satisfactory clinical outcome.

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Unicompartmental knee arthroplasty (UKA) is a reliable surgical procedure for patients with end-stage unicompartmental osteoarthritis or osteonecrosis, with fewer complications and faster recovery compared with total knee arthroplasty (TKA).[1]

As UKA is a technically demanding procedure, there is interest in the use of robotic-arm assistance to improve the position of the components and, potentially, the clinical outcome.[2-4] The aims of robotic-arm assistance are to simplify the procedure, to reduce the instrumentation, and to improve precision in bone preparation.[5] Recent studies have demonstrated that robotic-arm assisted systems show higher reliability over UKA performed using conventional intervention,[2,5,6] and studies to date have shown good patient satisfaction and revision rates for robotic-arm assisted UKA.[7,8]

A number of surgical parameters, including implant position, accurate sizing, ligament balancing, and restoration of limb alignment and joint line, have been shown to influence the outcome of fixed-bearing UKA.[9,10] By convention, the surgeon should aim for slight under-correction of the preoperative varus deformity in medial UKA.[11,12] In terms of tibial implant position, multiple studies have highlighted that leaving the medial tibial plateau with varus alignment results in high failure rates,[13] and leaving an increased posterior slope has been associated with risks of loosening.[14] Medial overhang of the tibial component also results in poorer outcomes.[15] Coronal malalignment of the

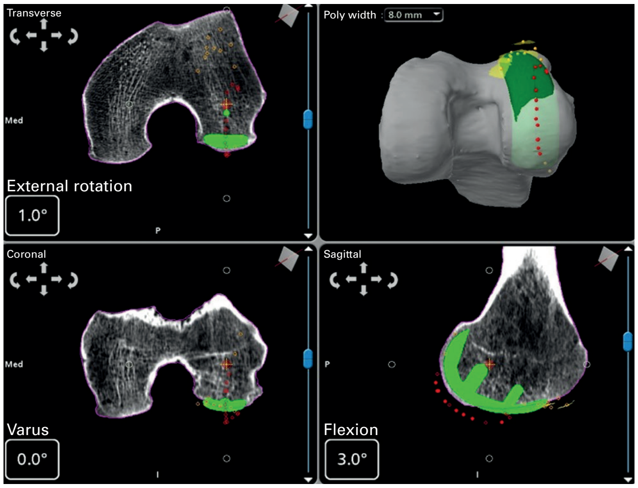

Fig. 1

Intraoperative planning of femoral component's placement in the 3D planes.

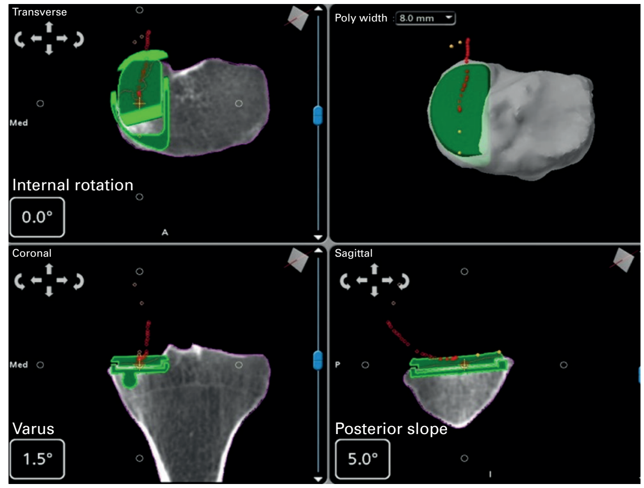

Fig. 2

Intraoperative planning of tibial component's placement in the 3D planes.

femoral component may result in overload of the lateral compartment, excessive load on the tibial insert, or medial collateral ligament strain.[16]

The primary aim of this multicentre observational study was to investigate the association of intraoperative component positioning and soft-tissue balancing on short-term clinical outcomes in patients undergoing robotic-arm assisted UKA. We hypothesized that short-term clinical outcomes would be affected by the placement of the components and the tension of the ligaments throughout the range of movement (ROM).

Patients and Methods

Study design. All consecutive patients undergoing robotic-arm assisted medial UKA at two centres between January 2013 and November 2016 were included in this retrospective observational study.

All patients received a fixed-bearing metal-backed UKA (Restoris MCK, Stryker, Mahwah, New Jersey) implanted with the MAKO robotic arm system (Stryker) using a minimally invasive mid-vastus approach by one of three high-volume UKA surgeons (GF, RN, FC). The MAKO is a third-generation haptic robotic arm and the accuracy of this system has been described in previous studies.[5,6] The surgical technique was consistent between the two centres.

Patients were eligible for study inclusion if they had a diagnosis of primary unicompartmental osteoarthritis or post-traumatic medial osteoarthritis or osteonecrosis, with no prior history of arthroplasty on the affected side. Exclusion criteria were as follows: prior history of osteotomy on the affected knee, coronal plane deformity > 15°, flexion contracture > 15°, functional incompetence of the anterior cruciate ligament (ACL) or collateral ligaments, and the presence of inflammatory arthropathies or conditions determining inability to adhere to the study protocol. In all, 363 patients (395 knees) underwent robotic-arm assisted tibiofemoral medial UKA. Three patients were excluded for prior history of osteotomy, four patients declined study participation, and three patients presented concomitant medical conditions influencing the clinical outcome, leaving 353 patients (385 knees), of whom 253 patients (65.7%) had at least two years of follow-up.

Preoperatively, all patients underwent a CT scan. After segmentation, a preoperative CT-based plan was produced. 3D component positioning was templated based upon preoperative radiological assessment and CT-based patients' anatomy. Implant position was modified intraoperatively based on the individual soft-tissue balancing.

Clinical data collection. In line with the institutions' standard of care, all patients were administered a complete clinical evaluation and asked to complete patient-reported outcome measures. The validated Italian version of the Knee Injury and Osteoarthritis Score (KOOS)[17] and the Forgotten Joint Score-12 (FJS-12)[18] were used in this study to target pain, joint mobility, and joint awareness.

All patients received similar postoperative rehabilitation protocols. All consented patients were evaluated at 3, 6, and 12 months of follow-up, and then annually.

Implant revision and reoperations were collected. Patients who did not attend two consecutive follow-up visits were considered lost to follow-up.

Clinical results were dichotomized based upon KOOS and FJS-12 scores into either good or poor outcome, considering a good KOOS and FJS-12 to be more than or equal to 80. The stratification was done considering the results of FJS-12 and of each subscale of KOOS separately, and as an independent value. This subdivision was made to investigate the association between intraoperative component positioning and soft-tissue balancing on clinical outcomes.

Intraoperative robotic data collection. Component positioning was expressed relative to femoral and tibial axes defined by the robotic system using the preoperative CT. We recorded the following data: coronal plane alignment of the femoral component relative to the mechanical axis of the femur; rotation of the femoral component relative to the transepicondylar axis; flexion/extension of the femoral component, expressed as the

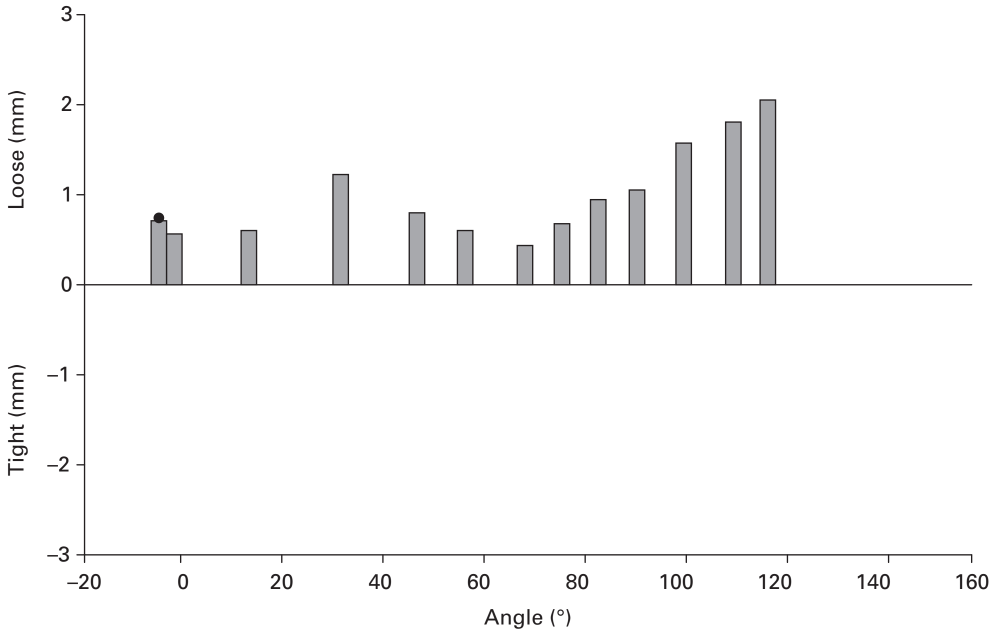

Fig. 3

Intraoperative ligament balancing based on femorotibial gaps through knee range of movement. The dot located at the top of the leftmost column represents the knee real-time flexion degree.

Table I. Definition of intraoperative robotic data into five classes. Positive values are expression of valgus alignment, external rotation, flexion (°), and ligament laxity (mm)

Definition	Intraoperative robotic positioning classes				
	A	B	C	D	E
Femoral component, °					
Internal/external rotation	< -3	-3 ≤ n < -1	-1 ≤ n ≤ 1	1 < n ≤ 3	> 3
Varus/valgus	< -3	-3 ≤ n < -1	-1 ≤ n ≤ 1	1 < n ≤ 3	> 3
Flexion/extension	< -1	-1 ≤ n < 1	1 ≤ n ≤ 3	3 < n ≤ 5	> 5
Tibial component, °					
Internal/external rotation	< -1	-1 ≤ n < 1	1 ≤ n ≤ 3	3 < n ≤ 5	> 5
Varus/valgus	< -3	-3 ≤ n < -2	-2 ≤ n ≤ 0	0 < n ≤ 2	> 2
Posterior slope	< 3	3 ≤ n < 4	4 ≤ n ≤ 6	6 < n ≤ 7	> 7
Lower limb mechanical alignment, °					
Before surgery (extension)	< -4	-4 ≤ n < -2	-2 ≤ n ≤ 0	0 < n ≤ 2	> 2
After surgery (extension)	< -4	-4 ≤ n < -2	-2 ≤ n ≤ 0	0 < n ≤ 2	> 2
Soft-tissue balancing, mm*					
(a): 0° to 10°	< -1	-1 ≤ n < 0	0 ≤ n ≤ 1	1 < n ≤ 2	> 2
(b): 20° to 30°	< -1	-1 ≤ n < 0	0 ≤ n ≤ 1	1 < n ≤ 2	> 2
(c): 50° to 60°	< -1	-1 ≤ n < 0	0 ≤ n ≤ 1	1 < n ≤ 2	> 2
(d): 80° to 90°	< -1	-1 ≤ n < 0	0 ≤ n ≤ 1	1 < n ≤ 2	> 2
(e): 110° to 120°	< -1	-1 ≤ n < 0	0 ≤ n ≤ 1	1 < n ≤ 2	> 2

*(a) 25 cases (knees) had missing data; (b) 18 cases had missing data; (c) 23 cases had missing data; (d) 12 cases had missing data; (e) 94 cases had missing data

angle resulting from the difference between 45° (inclination of the pegs relative to the femoral posterior axis component) and the angle subtended by the femoral implant peg axis and the femoral sagittal mechanical axis (Fig. 1); coronal alignment of the tibial component relative to the tibial mechanical axis; rotation of the tibial component, expressed as the angle between tibial anteroposterior (AP) axis and component AP axis; and posterior slope of the tibial component, expressed as the angle between the perpendicular to tibial sagittal mechanical axis and the tangent line to the tibial implant (Fig. 2). Gaps between femoral and tibial components were collected throughout the ROM. Intraoperative femorotibial gap was recorded at the intervals 0° to 10°, 20° to 30°, 50° to 60°, 80° to 90°, and 110° to 120° of knee flexion (Fig. 3).[19] Finally, the mechanical alignment of the lower limb was recorded pre- and intraoperatively.

Post-implantation robotic data were divided into five clusters based upon intraoperative 3D component positioning and tibiofemoral gaps at different degrees of knee flexion (Table I).

Table II. Pre- and postoperative clinical outcomes for Knee Injury and Osteoarthritis Score (KOOS) and Forgotten Joint Score-12 (FJS-12), number of cases with "good" clinical outcomes (≥ 80), and difference between pre- and postoperative clinical scores

Clinical score	**Preoperative**	**Postoperative**		**Postoperative – preoperative difference**	
	Mean (SD; range)	**Mean (SD; range)**	**Good (≥ 80), n (%)**	**Mean (SD; range)**	**p-value***
KOOS symptoms and stiffness	58.2 (17.0; 3.6 to 100.0)	92.8 (14.9; 14.3 to 100.0)	288 (*86.2*)	34.6 (20.6; -50.0 to 85.7)	< 0.001
KOOS pain	35.4 (17.2; 0.0 to 100.0)	89.1 (20.1; 0.0 to 100.0)	274 (*82.0*)	53.7 (26.0; -37.5 to 100.0)	< 0.001
KOOS function in activities of daily living	29.4 (16.9; 0.0 to 86.8)	82.7 (25.3; 0.0 to 100.0)	253 (*75.7*)	53.3 (29.9; -86.8 to 98.5)	< 0.001
KOOS function in sports and recreation	2.3 (8.4; 0.0 to 88.0)	20.6 (27.5; 0.0 to 100.0)	30 (*9.0*)	18.3 (27.6; -68.0 to 100.0)	< 0.001
KOOS quality of life	27.0 (13.9; 0.0 to 100.0)	80.9 (22.1; 0.0 to 100.0)	225 (*67.4*)	53.9 (25.5; -31.5 to 100.0)	< 0.001
Total KOOS	34.0 (13.2; 6.1 to 74.1)	85.5 (17.1; 6.1 to 100.0)	268 (*80.2*)	51.5 (21.2; -15.2 to 93.9)	< 0.001
FJS-12	18.1 (15.3; 0.0 to 91.6)	81.4 (27.7; 0.0 to 100.0)	224 (*67.1*)	63.3 (31.8; -31.8 to 100.0)	< 0.001

*Matched-pairs Wilcoxon's signed-rank test

Table III. Intraoperative robotic parameters relative to component placement, lower limb mechanical alignment, and soft-tissue balancing information. Positive values are expression of valgus alignment, external rotation, flexion, and ligament laxity. Positioning parameters are expressed in classes according to subdivision made in Table I

Definition	**Mean (SD; range)**	**Intraoperative robotic positioning classes: knees, n (%)**				
		A	**B**	**C**	**D**	**E**
Femoral component, °						
Internal/external rotation	0.7 (1.3; -4 to 7)	2 (*0.6*)	13 (*4*)	234 (*71.8*)	77 (*23.6*)	8 (*2.5*)
Varus/valgus	0.3 (1.5; -4 to 12)	4 (*1.2*)	32 (*9.7*)	232 (*70.3*)	62 (*18.8*)	4 (*1.2*)
Flexion/extension	3.7 (3.1; -6 to 16)	8 (*3.3*)	42 (*17.2*)	113 (*46.3*)	81 (*33.2*)	90 (*36.9*)
Tibial component, °						
Internal/external rotation	2.1 (1.8; -13 to 8)	4 (*1.2*)	49 (*14.8*)	248 (*74.9*)	30 (*9.1*)	3 (*0.9*)
Varus/valgus	-1.4 (0.8; -4 to 6)	4 (*1.2*)	21 (*6.3*)	300 (*90.1*)	8 (*2.4*)	1 (*0.3*)
Posterior slope	5.1 (1.0; 2 to 8)	6 (*1.8*)	19 (*5.7*)	280 (*84.6*)	26 (*7.9*)	3 (*0.9*)
Lower limb mechanical alignment, °						
Before surgery (extension)	-6.5 (3.3; -15 to 10)	257 (*78.4*)	55 (*16.8*)	14 (*4.3*)	2 (*0.6*)	6 (*1.8*)
After surgery (extension)	-3.1 (2.5; -15 to 3.5)	97 (*29.5*)	103 (*31.3*)	124 (*37.7*)	5 (*1.5*)	5 (*1.5*)
Soft-tissue balancing, mm*						
(a): 0° to 10°	0.3 (0.9; -2 to 3)	14 (*4.5*)	62 (*20.1*)	228 (*73.8*)	5 (*1.6*)	0 (*0*)
(b): 20° to 30°	1.6 (0.8; -0.5 to 3)	0 (*0*)	5 (*1.9*)	94 (*36.3*)	160 (*61.8*)	57 (*22*)
(c): 50° to 60°	0.5 (0.7; -1.5 to 2.5)	3 (*1*)	42 (*13.8*)	222 (*72.8*)	38 (*12.5*)	6 (*2*)
(d): 80° to 90°	0.4 (0.7; -2 to 2)	3 (*0.9*)	48 (*14.9*)	235 (*73*)	36 (*11.2*)	0 (*0*)
(e): 110° to 120°	0.9 (0.9; -2 to 3)	3 (*1.3*)	19 (*8.5*)	143 (*64.1*)	58 (*26*)	17 (*7.6*)

*(a) 25 cases (knees) had missing data; (b) 18 cases had missing data; (c) 23 cases had missing data; (d) 12 cases had missing data; (e) 94 cases had missing data

Statistical analysis. Descriptive statistics were presented, including numbers and percentages for categorical data and means and standard deviations for continuous variables. The primary outcomes were overall KOOS and FJS-12, while KOOS subscales were secondary outcomes. Wilcoxon's signed-rank tests were used to compare preoperative and postoperative clinical scores. The association between the intraoperative parameters (in classes as previously defined) and the outcomes was assessed by means of logistic regression models. The dichotomous dependent variable was postoperative outcome score (good/poor), while independent variables were the intraoperative parameter of interest and the preoperative clinical score. Every intraoperative class that had fewer than ten observations was merged with its adjacent class. One model was estimated for each outcome measure and for each intraoperative parameter. Results are reported as odds ratios (OR) for the probability of having a good outcome, with 95% confidence intervals (CI) and p-values. Finally, Kaplan–Meier survival curves were calculated, considering reoperation for all causes and revision as the events of interest. All tests were two-sided with a p-value < 0.05 defining significance. Since this was an exploratory study, no multiple comparisons adjustment was made. Analyses were performed with R 3.4.3 statistical software (The R Foundation for Statistical Computing, Vienna, Austria).

Results

Of the 353 patients (385 knees), 305 patients (334 knees, 86.8%: 132 male patients, 43.3%; 173 female patients, 56.7%) were included in the clinical outcome analysis (75.1% with at least two years of follow-up); the remaining 51 knees (13% of the total) were excluded due to missing intraoperative or postoperative outcome data.

All 353 patients (385 knees) included for assessment were taken into account in the survival analysis.

The preoperative diagnosis was primary osteoarthritis in 277 knees, post-traumatic osteoarthritis in six knees, osteonecrosis in 26 knees, and post-meniscectomy osteoarthritis or osteonecrosis in the remaining 25 knees. Eight patients treated with medial UKA had undergone previous ACL reconstruction.

Table IV. Association between intraoperative robotic parameters expressed in classes, according to subdivision made in Table I, and clinical outcomes: overall Knee Injury and Osteoarthritis Score (KOOS) and Forgotten Joint Score-12 (FJS-12)

Intraoperative robotic parameter		Overall KOOS		FJS-12	
		OR (95% CI)	p-value*	OR (95% CI)	p-value*
Femoral component					
Internal/external rotation	B/A *vs* C	1.6 (0.3 to 7.4)	0.543	1.3 (0.4 to 4.3)	0.639
	D/E *vs* C	0.9 (0.5 to 1.7)	0.785	0.8 (0.5 to 1.4)	0.448
Varus/valgus	B/A *vs* C	2.2 (0.7 to 6.5)	0.159	1.8 (0.8 to 4.0)	0.189
	D/E *vs* C	1.2 (0.6 to 2.5)	0.539	0.7 (0.4 to 1.3)	0.314
Flexion/extension	B/A *vs* C	1.0 (0.4 to 2.5)	0.993	1.1 (0.5 to 2.4)	0.773
	D *vs* C	0.5 (0.3 to 1.0)	0.061	0.5 (0.3 to 1.0)	0.034†
	E *vs* C	0.8 (0.4 to 1.6)	0.459	0.8 (0.4 to 1.4)	0.438
Tibial component					
Internal/external rotation	B/A *vs* C	1.4 (0.6 to 3.2)	0.411	0.9 (0.5 to 1.7)	0.762
	D/E *vs* C	0.8 (0.3 to 1.9)	0.599	0.7 (0.3 to 1.5)	0.404
Varus/valgus	B *vs* C/D/E	1.9 (0.6 to 6.7)	0.295	0.5 (0.2 to 1.1)	0.098
Posterior slope	B/A *vs* C	1.9 (0.5 to 6.5)	0.323	1.2 (0.5 to 3.1)	0.650
	D/E *vs* C	1.0 (0.4 to 2.5)	0.957	0.7 (0.3 to 1.5)	0.338
Lower limb mechanical alignment					
Before surgery (extension)	B *vs* C/D/E	1.5 (0.5 to 4.5)	0.462	0.8 (0.3 to 2.2)	0.678
	A *vs* C/D/E	2.2 (0.8 to 5.6)	0.111	1.3 (0.5 to 3.2)	0.564
After surgery (extension)	B *vs* C/D/E	1.5 (0.8 to 2.8)	0.245	1.3 (0.7 to 2.2)	0.404
	A *vs* C/D/E	1.6 (0.8 to 3.1)	0.175	1.4 (0.8 to 2.4)	0.283
Soft-tissue balancing‡					
(a): 0° to 10°	B *vs* C/D	1.4 (0.7 to 2.9)	0.390	1.5 (0.8 to 2.7)	0.226
	A *vs* C/D	1.0 (0.3 to 3.7)	0.989	0.7 (0.2 to 2.2)	0.583
(b): 20° to 30°	D *vs* C/B	1.3 (0.7 to 2.4)	0.409	1.3 (0.8 to 2.3)	0.264
	E *vs* C/B	1.7 (0.7 to 4.0)	0.207	1.5 (0.7 to 3.0)	0.257
(c): 50° to 60°	B/A *vs* C	0.6 (0.3 to 1.2)	0.166	0.6 (0.3 to 1.1)	0.122
	D/E *vs* C	1.3 (0.5 to 3.1)	0.560	1.2 (0.6 to 2.3)	0.694
(d): 80° to 90°	B/A *vs* C	0.8 (0.4 to 1.7)	0.619	0.8 (0.4 to 1.5)	0.460
	D *vs* C	0.8 (0.3 to 1.9)	0.618	2.1 (0.9 to 5.1)	0.088
(e): 110° to 120°	B/A *vs* C	5.4 (0.7 to 42.1)	0.105	1.6 (0.6 to 4.7)	0.375
	D *vs* C	2.7 (1.0 to 7.4)	0.053	1.2 (0.6 to 2.3)	0.620
	E *vs* C	0.8 (0.3 to 2.7)	0.756	0.9 (0.3 to 2.5)	0.791

*Logistic regression model
†Statistically significant
‡(a) 25 missing records; (b) 18 missing records; (c) 23 missing records; (d) 12 missing records; (e) 94 missing records
OR, odds ratio; CI, confidence interval

The mean age and body mass index (BMI) of the selected cohort at the time of implant were 65.6 years (40.0 to 83.0) and 28.5 kg/m^2 (16.1 to 46.9), respectively. The mean follow-up was 30.0 months (8.0 to 54.9) postoperatively.

All postoperative clinical scores showed statistically significant improvement compared with the preoperative evaluation in FJS-12 and the KOOS subscales (Table II).

The mean alignment of the femoral and tibial components, as well as pre- and post-implantation lower limb alignment and intraoperative femorotibial gaps at different degrees of knee flexion, are reported in Table III.

There was no correlation between component position or soft-tissue balancing and overall KOOS score (Table IV). For KOOS subscales, associations were described for femoral component alignment in the coronal and sagittal planes, tibial component coronal alignment, and femorotibial gap of 20° to 30° and 110° to 120° of knee flexion (Table V).

With regard to FJS-12 score, values of femoral component flexion between 3° and 5° were associated with a lower probability of a good clinical outcome compared with other component flexion degrees (Table IV).

Three knees (three patients) were revised, resulting in a revision-free survival probability at three years from implantation equal to 99.0% (95% CI 97.9 to 100.0) (Fig. 4). Considering any reoperation as the endpoint, two more UKAs were included, determining an overall reoperation-free survival probability at three years from implant equal to 98.4% (95% CI 97.0 to 99.8). One UKA was revised for prosthetic joint infection, two cases were revised for tibial component aseptic loosening (fixation failure), and two patients reported synovial hypertrophy that was treated by arthroscopic debridement.

Discussion

This study failed to demonstrate any relationship between component position, soft-tissue balancing, and overall KOOS outcomes. Breaking the KOOS into subscales, some clinical subscales were affected by intraoperative variables; the clinical significance of this is uncertain (Table II). Increased flexion of

Table V. Association between intraoperative robotic parameters expressed in classes, according to subdivision made in Table I, and clinical outcomes by Knee Injury and Osteoarthritis Score (KOOS) subscales

Intraoperative robotic parameter		KOOS – symptoms and stiffness		KOOS – pain		KOOS – function in activities of daily living		KOOS – function in sports and recreation		KOOS – quality of life	
		OR (95% CI)	p-value*	OR (95% CI)	p-value*	OR (95% CI)	p-value*	OR (95% CI)	p-value*	OR (95% CI)	p-value*
Femoral component											
Internal/external rotation	B/A *vs* C	0.9 (0.2 to 4.0)	0.838	0.6 (0.2 to 1.9)	0.349	2.1 (0.4 to 9.4)	0.353	1.5 (0.3 to 6.9)	0.638	1.3 (0.4 to 4.2)	0.661
	D/E *vs* C	0.7 (0.4 to 1.5)	0.370	0.9 (0.5 to 1.7)	0.733	0.8 (0.5 to 1.5)	0.567	0.3 (0.1 to 1.2)	0.089	0.9 (0.5 to 1.5)	0.574
Varus/valgus	B/A *vs* C	6.2 (0.8 to 47.5)	0.077	0.9 (0.4 to 2.3)	0.842	2.0 (0.7 to 5.4)	0.175	1.7 (0.6 to 4.9)	0.323	1.0 (0.5 to 2.0)	0.905
	D/E *vs* C	0.7 (0.3 to 1.4)	0.329	0.5 (0.3 to 0.9)	0.032†	0.7 (0.4 to 1.3)	0.298	0.5 (0.1 to 1.7)	0.253	1.0 (0.5 to 1.7)	0.876
Flexion /extension	B/A *vs* C	1.1 (0.4 to 3.2)	0.906	0.8 (0.3 to 2.0)	0.646	1.6 (0.7 to 3.8)	0.311	0.3 (0.1 to 1.3)	0.096	2.6 (1.1 to 5.9)	0.022†
	D *vs* C	0.5 (0.2 to 1.2)	0.147	0.9 (0.4 to 2.1)	0.865	0.7 (0.4 to 1.3)	0.291	0.7 (0.2 to 1.7)	0.390	0.8 (0.5 to 1.5)	0.524
	E *vs* C	0.6 (0.3 to 1.4)	0.223	0.6 (0.3 to 1.2)	0.134	0.9 (0.5 to 1.7)	0.673	0.6 (0.2 to 1.5)	0.279	1.4 (0.8 to 2.6)	0.262
Tibial component											
Internal/external rotation	B/A *vs* C	1.2 (0.5 to 3.1)	0.642	1.4 (0.6 to 3.3)	0.431	0.8 (0.4 to 1.7)	0.633	1.4 (0.5 to 3.6)	0.501	1.9 (0.9 to 3.8)	0.074
	D/E *vs* C	1.1 (0.4 to 3.3)	0.871	0.6 (0.3 to 1.3)	0.207	0.8 (0.4 to 1.8)	0.610	0.7 (0.2 to 3.2)	0.665	1.5 (0.7 to 3.3)	0.357
Varus/valgus	B *vs* C/D/E	0.8 (0.3 to 2.6)	0.766	0.9 (0.3 to 2.5)	0.829	0.4 (0.2 to 1.0)	0.047†	4.4 (1.6 to 12.0)	0.003†	1.3 (0.5 to 3.1)	0.620
Posterior slope	B/A *vs* C	1.0 (0.3 to 3.1)	0.981	0.7 (0.2 to 1.7)	0.401	1.7 (0.6 to 5.3)	0.324	0.4 (0.0 to 2.9)	0.343	1.9 (0.7 to 5.3)	0.204
	D/E *vs* C	1.5 (0.4 to 5.1)	0.551	1.0 (0.4 to 2.8)	0.973	1.0 (0.4 to 2.6)	0.923	N/A	N/A	0.6 (0.3 to 1.3)	0.188
Lower limb mechanical alignment											
Before surgery (extension)	B *vs* C/D/E	1.1 (0.3 to 3.7)	0.865	1.3 (0.4 to 4.4)	0.660	1.4 (0.5 to 4.0)	0.582	0.5 (0.1 to 2.2)	0.392	1.1 (0.4 to 3.1)	0.823
	A *vs* C/D/E	2.0 (0.7 to 5.9)	0.211	1.4 (0.5 to 4.0)	0.540	1.5 (0.6 to 3.9)	0.385	0.4 (0.1 to 1.2)	0.087	1.6 (0.6 to 3.8)	0.328
After surgery (extension)	B *vs* C/D/E	1.2 (0.5 to 2.5)	0.709	1.7 (0.8 to 3.4)	0.159	1.2 (0.7 to 2.2)	0.559	0.6 (0.2 to 1.5)	0.270	1.3 (0.7 to 2.2)	0.411
	A *vs* C/D/E	1.0 (0.5 to 2.0)	0.929	1.2 (0.6 to 2.2)	0.664	1.0 (0.6 to 1.9)	0.914	0.7 (0.3 to 1.7)	0.380	1.2 (0.7 to 2.0)	0.616
Soft-tissue balancing‡											
(a): 0° to 10°	B *vs* C/D	1.1 (0.5 to 2.6)	0.793	0.9 (0.4 to 1.8)	0.691	1.1 (0.5 to 2.1)	0.872	1.5 (0.6 to 3.8)	0.384	1.2 (0.6 to 2.1)	0.637
	A *vs* C/D	1.0 (0.2 to 4.9)	0.957	0.4 (0.1 to 1.2)	0.106	0.4 (0.1 to 1.2)	0.100	3.4 (0.9 to 13.3)	0.081	0.9 (0.3 to 2.8)	0.835
(b): 20° to 30°	D *vs* C/B	1.8 (0.9 to 3.5)	0.110	2.2 (1.2 to 4.3)	0.014†	1.8 (1.0 to 3.1)	0.042†	1.0 (0.4 to 2.3)	0.909	1.0 (0.6 to 1.8)	0.873
	E *vs* C/B	1.6 (0.6 to 4.2)	0.302	1.8 (0.8 to 4.2)	0.171	2.1 (1.0 to 4.6)	0.063	0.7 (0.2 to 2.4)	0.587	1.3 (0.6 to 2.6)	0.481
(c): 50° to 60°	B/A *vs* C	1.1 (0.4 to 2.8)	0.872	0.7 (0.3 to 1.6)	0.458	0.5 (0.3 to 1.1)	0.081	1.0 (0.3 to 3.2)	0.964	0.6 (0.3 to 1.2)	0.151
	D/E *vs* C	1.5 (0.5 to 4.0)	0.455	0.8 (0.4 to 1.8)	0.626	1.5 (0.7 to 3.4)	0.337	0.9 (0.3 to 3.0)	0.916	0.9 (0.4 to 1.7)	0.708
(d): 80° to 90°	B/A *vs* C	0.7 (0.3 to 1.6)	0.409	0.5 (0.3 to 1.1)	0.096	0.6 (0.3 to 1.1)	0.079	0.8 (0.3 to 2.4)	0.686	0.7 (0.4 to 1.3)	0.299
	D *vs* C	0.8 (0.3 to 2.1)	0.642	0.6 (0.3 to 1.5)	0.311	1.0 (0.4 to 2.3)	0.940	0.6 (0.1 to 2.6)	0.479	0.5 (0.3 to 1.1)	0.082
(e): 110° to 120°	B/A *vs* C	4.3 (0.5 to 34.0)	0.166	4.0 (0.5 to 31.4)	0.185	3.4 (0.7 to 15.1)	0.114	0.8 (0.2 to 4.0)	0.830	1.4 (0.5 to 3.9)	0.467
	D *vs* C	3.4 (1 to 11.8)	0.058	1.0 (0.5 to 2.4)	0.921	1.1 (0.6 to 2.4)	0.713	1.0 (0.4 to 2.9)	0.932	2.1 (1.0 to 4.3)	0.048†
	E *vs* C	1.7 (0.3 to 8.0)	0.530	0.6 (0.2 to 2.1)	0.442	1.1 (0.3 to 3.6)	0.887	1.1 (0.2 to 5.4)	0.900	1.3 (0.4 to 3.8)	0.667

*Logistic regression model
†Statistically significant
‡(a) 25 missing records; (b) 18 missing records; (c) 23 missing records; (d) 12 missing records; (e) 94 missing records
OR, odds ratio; CI, confidence interval; N/A, not applicable due to lack of outcome events in one of the subgroups

the femoral component was found to be associated with a lower probability of obtaining a good outcome on FJS-12 (Table IV).

Compared with the tibia,[12] the influence of femoral component alignment has received little attention in the literature.[15] According to the present study, knees with neutral femoral component coronal alignment are likely to obtain better results in the 'pain' KOOS subscales compared with patients with femoral component in valgus (Table V). On the other hand, contradictory outcome associations were reported for tibial component coronal alignment. As with the other findings on KOOS subscales, these associations may well be due to chance, secondary to the multiple testing effect. However, the importance of this parameter influencing function and longevity of UKA is well known and the small number of outliers may confirm the consistency of robotic assistance in UKA component placement.

Tibial slope had a mean of 5.1° and did not correlate with any of the clinical outcome scores. Concerning femoral component sagittal alignment, those patients who had slight femoral component flexion (between 1° and 3°) were more likely to have good outcome scores in the FJS-12 and KOOS quality of life subscales, but again this may be due to chance. To achieve physiological knee kinematics and to optimize ROM, surgeons should aim to maintain the native femoral flexion, as modification of the posterior femoral condylar offset can result in impaired knee flexion.[20] Rotational alignment of the tibia and femur did not affect any of the outcome measures. The mean values for external rotation of the femoral and tibial components (0.7° and 2.1°, respectively) would be considered to be favourable for long-term function and survival.[21]

Robotic assistance permits real-time and dynamic ligamentous balancing throughout the full ROM of the knee.[18] In regard to ligament balancing in the present series of robotic-arm assisted UKAs, associations with good clinical outcome were

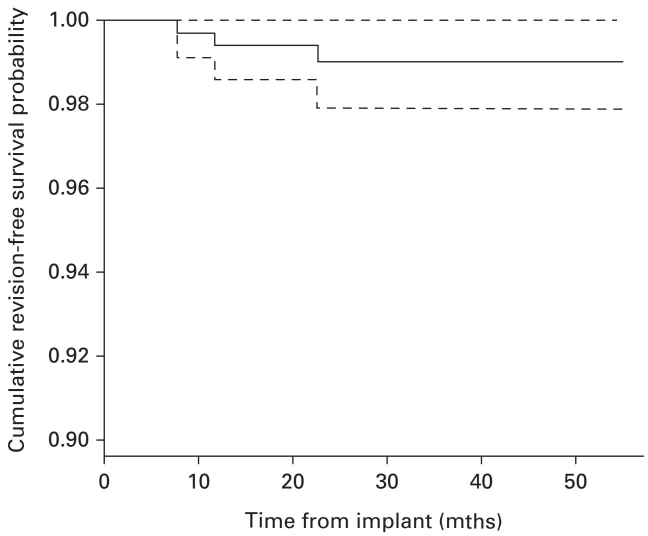

Fig. 4

Kaplan–Meier revision-free survival probability of robotic-arm assisted medial unicompartmental knee arthroplasties (UKAs), considering revision as the endpoint. Dashed lines represent 95% confidence intervals.

reported only for ligament tensioning between 20° and 30° of knee flexion in the 'pain' subscale and 'function in ADL' subscale, and between 110° and 120° of flexion in the 'quality of life' subscale. Approximately 1.5 mm of gap laxity at these degrees of knee flexion was associated with a higher probability of better outcome. Relative to ligament balancing curves, relative tightness was typically obtained in full extension, and slight laxity was described between 20° and 30° of flexion, followed by relative tightness (femorotibial gap < 1 mm) between 50° and 90° of flexion. Beyond 90° of flexion, the mean relative laxity was noted, with approximately 1.0 mm of femorotibial gap (Table III).

The mean intraoperative pre-implant coronal deformity was 6.4° varus, corrected to 3.0° varus after component positioning. As suggested by the literature, preoperative knee deformity was not fully corrected, and some degrees of residual varus were reported after surgery.[10,11,22,23]

The low number of associations between intraoperative component placement and clinical result may be attributed to the small number of alignment outliers in this data set (Table III). This finding could be motivated by the higher reliability of robotic assistance in bone preparation over manual UKA.

The present study has limitations. The most important limitation was the short follow-up (75.1% of all UKAs with at least two years' follow-up). In addition, 13.2% of patients were lost to follow-up, leaving 86.8% for final analysis. A third limitation was due to the nature of the multicentre study design, and variability in surgeon-to-surgeon case-planning. The preoperative planning, changes made intraoperatively, and ligament balancing were left to the discretion of each surgeon. This could not be standardized, as this is patient-specific based on anatomy, laxity, and severity of the osteoarthritic disease. Furthermore, no radiographs were reviewed, thus differences in preoperative grade of osteoarthritis were not examined. Lastly, the outcome measures used may not properly detect the differences between patients with insufficient or excellent clinical results. The KOOS and FJS-12 were selected due to their widespread acceptance and use in assessing knee arthroplasty. However, there is little evidence that these scores, or any other clinical outcome measure, have been validated specifically for use in the assessment of UKA.

In conclusion, although few correlations were found between intraoperative robotic data and overall clinical outcome, surgeons should consider information regarding UKA 3D component placement and soft-tissue balancing to improve patient satisfaction. Robotic-arm assistance confirmed high consistency in UKA positioning.

Take home message

- This study shows the survivorship of medial robotic-arm assisted partial knee arthroplasty at short-term follow-up.
- This study is the first in the literature to describe the correlation between intraoperative unicompartmental knee arthroplasty (UKA) 3D component positioning, soft-tissue balancing, and patient-reported outcome measures.

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