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Restoration or relative overcorrection of pre-arthritic coronal alignment leads to improved results following medial unicompartmental knee arthroplasty

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Abstract

Purpose A pre-arthritic alignment strategy for medial unicompartmental knee arthroplasty (UKA) aims to restore a patient's native lower limb alignment which may translate into improved outcomes. This study aimed to assess whether patients with pre-arthritically aligned knees versus patients with non-pre-arthritically aligned knees demonstrated improved mid-term outcomes and survivorship following medial UKA. The hypothesis was that pre-arthritic alignment in medial UKA would lead to better postoperative outcomes.

Methods A retrospective study of 537 robotic-assisted fixed-bearing medial UKA was conducted. During this procedure, the surgical goal was to restore pre-arthritic alignment guided by re-tensioning of the medial collateral ligament (MCL). For study purposes, coronal alignment was retrospectively evaluated using the mechanical hip-knee-ankle angle (mHKA). Pre-arthritic alignment was estimated through the arithmetic hip-knee-ankle (aHKA) algorithm. Knees were grouped according to the difference between postoperative mHKA and estimated pre-arthritic alignment (i.e., mHKA - aHKA) as Group 1 (pre-arthritically aligned: mHKA restored within 2.0° of the aHKA), Group 2 (mHKA > 2.0° overcorrected relative to the aHKA), or Group 3 (mHKA > 2.0° undercorrected relative to the aHKA). Outcomes included the Knee Injury and Osteoarthritic Outcome Score for Joint Replacement (KOOS, JR), Kujala, proportions of knees achieving the patient acceptable symptom state (PASS) for these scores, and survivorship. PASS thresholds for KOOS, JR and Kujala were determined using a receiver operating characteristic curve method.

Results A total of 369 knees were categorized as Group 1, 107 as Group 2, and 61 as Group 3. At 4.4 ± 1.6 years follow-up, mean KOOS, JR was comparable among groups, while Kujala was significantly worse in Group 3. The proportion of knees achieving the PASS for Kujala (76.5 points) was lower in Group 3 ($n=32$; 59%) compared to Group 1 ($n=260$; 74%) ($p=0.02$). 5-year survivorship was higher in Group 1 and Group 2 (99% and 100%, respectively) compared to Group 3 (91%) ($p=0.04$).

Conclusion Pre-arthritically aligned knees and knees with relative overcorrection from their pre-arthritic alignment following medial UKA demonstrated improved mid-term outcomes and survivorship compared to knees with relative under correction from their pre-arthritic alignment. These results encourage restoring or relatively overcorrecting pre-arthritic alignment to optimize outcomes following medial UKA, and caution against under correction from the pre-arthritic alignment.

Level of evidence IV, case series.

Keywords Unicompartmental knee arthroplasty · Robotic-assisted surgery · Mechanical axis · Pre-arthritic alignment · Patient-reported outcomes · Survivorship

Introduction

Unicompartmental knee arthroplasty (UKA) is an effective surgical treatment for medial compartment osteoarthritis (OA), yielding successful functional outcomes, high satisfaction rates, and a fast postoperative recovery [2, 18,

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22]. Although UKA is an established procedure, there is currently no consensus with regard to optimal alignment strategies.

Traditionally, mechanical alignment has served as a straightforward approach that aimed to achieve a neutral mechanical axis following medial UKA [34]. This technique followed conventional total knee arthroplasty (TKA) concepts and was mainly based on biomechanical principles to prolong implant longevity and improve surgical reproducibility [14]. However, given the great variability in anatomy and coronal alignment phenotypes [3, 13, 14], it is likely that a great proportion of knees are corrected to an unnatural alignment following a systematic target approach [14]. Consequently, both postoperative knee kinematics and function may be compromised in these patients following medial UKA.

In contrast, individualized alignment strategies aim to recreate a patient's pre-arthritic alignment (i.e., prior to the onset of OA), often guided by re-tensioning of the medial collateral ligament (MCL). A recent study of 150 medial UKAs reported better long-term functional outcomes and implant survivorship of knees that were restored to their pre-arthritic alignment compared to knees that were not [25]. Similarly, individualized strategies in TKA also referred to as kinematic alignment, have been shown to yield improved postoperative clinical outcomes compared to mechanically aligned knees [19].

While an individualized, pre-arthritic alignment concept in knee arthroplasty appears promising, the supportive evidence for its use in medial UKA remains scarce. The present study aimed to assess whether patients with pre-arthritically aligned knees versus patients with non-pre-arthritically aligned knees following medial UKA demonstrated improved patient-reported outcomes and survivorship at mid-term follow-up. It was hypothesized that pre-arthritic alignment in medial UKA would lead to better postoperative outcomes.

Methods

Patients and study design

Following Institutional Review Board approval (#2021–2004), data were collected for 847 knees following robotic-assisted medial UKA, performed by a single surgeon (ADP) between November 2008 and August 2016. Patients were eligible for inclusion if they received primary medial UKA for medial compartment OA, and completed patient-reported outcome measures (PROMs) at a minimum of 2 years follow-up. Patients were excluded if they had incomplete radiographic records (pre- and postoperative long-leg radiographs), a history of fractures or joint arthroplasty on the operative side, or received an all-polyethylene tibial component. Additionally, the surgeon's alignment technique was restricted by neutral alignment to avoid lateral compartment degeneration. Patients with an estimated pre-arthritic alignment in valgus were therefore corrected to neutral alignment instead (i.e., mechanically aligned). Per definition, pre-arthritic alignment was not pursued in these cases and these patients were therefore excluded from the study. After the application of the exclusion criteria, a total of 537 knees were included (Fig. 1). Demographics are presented in Table 1.

The primary surgical indication for medial UKA was end-stage medial OA, with a varus deformity correctable

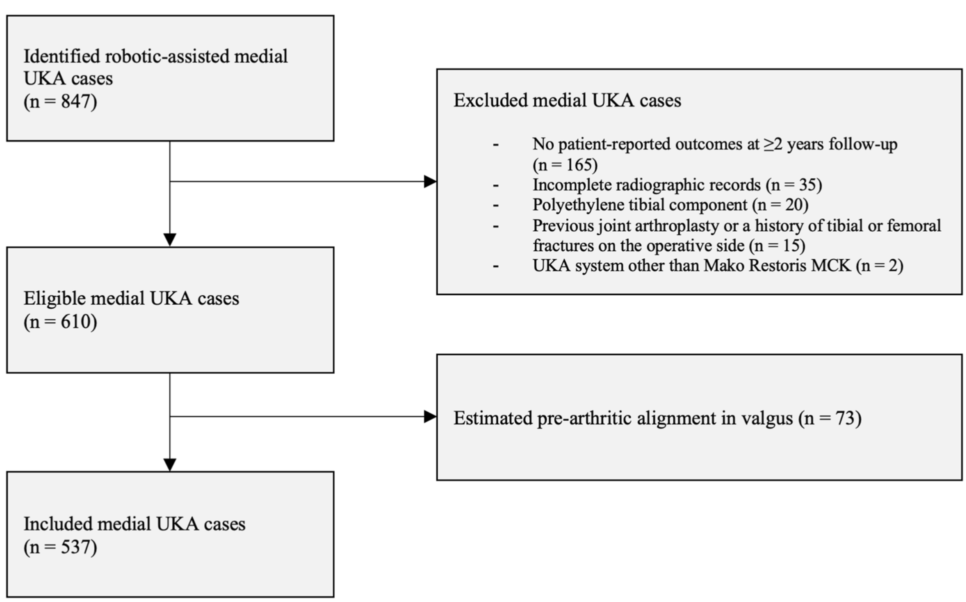

Fig. 1 Flowchart of patient inclusion

Table 1 Demographics and radiographic outcomes of included knees ($n = 537$)

	Mean ± SD or *n* (%)	Range
Demographics		
Follow-up (year)	4.4 ± 1.6	2.0 to 9.0
Age (year)	63.2 ± 9.0	41.4 to 86.8
BMI (kg/m^2)†	29.5 ± 5.2	17.5 to 46.0
Gender (male)	312 (58%)	
Radiographic outcomes		
Preoperative mHKA	7.9° ± 3.2°	−0.2 to 17.9
Postoperative mHKA	3.1° ± 2.1°	−3.1 to 10.6
MPTA	85.4° ± 2.1°	78.8 to 91.6
mLDFA	88.8° ± 2.0°	83.1 to 95.4
aHKA	3.1° ± 2.2°	−0.4 to 11.6

Demographics and radiographic outcomes are presented for all included knees as mean ± standard deviation (SD) or in numbers and frequencies. Ranges are provided for continuous variables

aHKA arithmetic hip-knee-ankle angle; *BMI* body mass index, *mLDFA* mechanical lateral distal femoral angle, *mHKA* mechanical hip-knee-ankle angle, *MPTA* medial proximal tibial angle

†BMI was missing for 51 knees

to < 10°, and fixed flexion deformity of < 10°. Surgical exclusion criteria included signs of substantial lateral compartment OA, lateral patellar facet degeneration, prior MCL surgery, anterior cruciate ligament deficiency with clinical instability, or signs of inflammatory arthritis.

Implant and surgical technique

All patients received a cemented medial UKA with a fixed-bearing tibial onlay implant (Restoris MCK System, Mako Surgical Corp. (Stryker), Fort Lauderdale, FL, USA). A robotic-arm assisted system (Mako Surgical Corp. (Stryker), Fort Lauderdale, FL, USA) was used for implant planning and preparation of the bone, according to a previously described technique [24, 29]. A computed tomography (CT) 3D model of the knee was registered to the patient's knee anatomy, allowing for virtual implant planning and real-time visual feedback during the procedure. The surgical goal was to restore the patient's pre-arthritic alignment, guided by re-tensioning of the MCL [1]. Implant position and thickness of the insert were chosen so that native MCL tension was restored throughout the range of motion (ROM) while simultaneously correcting the intra-articular deformity (i.e., resurfacing of the arthritic compartment). The robotic platform allowed the surgeon to alter and optimize the virtual implant position and MCL tension before any bony cuts were made. In general, the tibial component was positioned at 2° of varus with 5°–7° posterior slope [30]. The femoral component was planned to track centrally over the tibial component during ROM [15]. The knee was considered well-balanced if after placement of the insert, a valgus stress test in 30° of flexion demonstrated a 1–2 mm medial gap. Restoration of pre-arthritic alignment was bounded by neutral. Therefore, neutral alignment was pursued for patients with estimated valgus alignment, based on their MCL tension.

Radiographic assessment

Routine weight-bearing long-leg radiographs were obtained preoperatively and at 6 weeks postoperatively. When obtaining these radiographs, patients were instructed to stand with their feet together, body weight evenly distributed over both limbs, knees fully extended and patellae facing forward.

Estimation of pre-arthritic alignment

Pre-arthritic mechanical alignment was retrospectively estimated using the validated arithmetic hip-knee ankle (aHKA) algorithm [11] of the operative knee. The aHKA subtracts the preoperative mechanical lateral distal femoral angle (mLDFA) from the preoperative medial proximal tibial angle (MPTA; Fig. 2A). The mechanical hip-knee-ankle angle (mHKA) was measured pre- and post-operatively (Fig. 2B). All angles were measured to the tenth of a degree.

Restoration of pre-arthritic alignment

To evaluate the restoration of pre-arthritic alignment, postoperative mHKA was compared to the aHKA for each patient. A knee was considered pre-arthritically aligned if postoperative mHKA was restored within ± 2.0° of the aHKA [1]. Knees were divided into three groups based on the difference between their postoperative mHKA and aHKA: Group 1 (pre-arthritically aligned: mHKA restored within 2.0° of the aHKA; Fig. 3A), Group 2 (non-pre-arthritically aligned: mHKA > 2.0° overcorrected relative to the aHKA; Fig. 3B), or Group 3 (non-pre-arthritically aligned: mHKA > 2.0° undercorrected relative to the aHKA; Fig. 3C).

Radiographic measurements were independently performed by two observers (LVR and TB), using a Picture Archiving and Communication System (PACS, Sectra, Imtec AB, v16, Linköping, Sweden). Both observers were blinded to postoperative outcomes. Intraclass correlation coefficients (ICC), using a two-way mixed model with an absolute agreement, were good-to-excellent; ICC aHKA: 0.86 (95% confidence interval [CI] 0.80–0.90); ICC mHKA: 0.99 (95% CI 0.98–0.99).

Patient-reported outcome measures

The Knee Injury and Osteoarthritis Outcome Score for Joint Replacement (KOOS, JR), Kujala, and Western

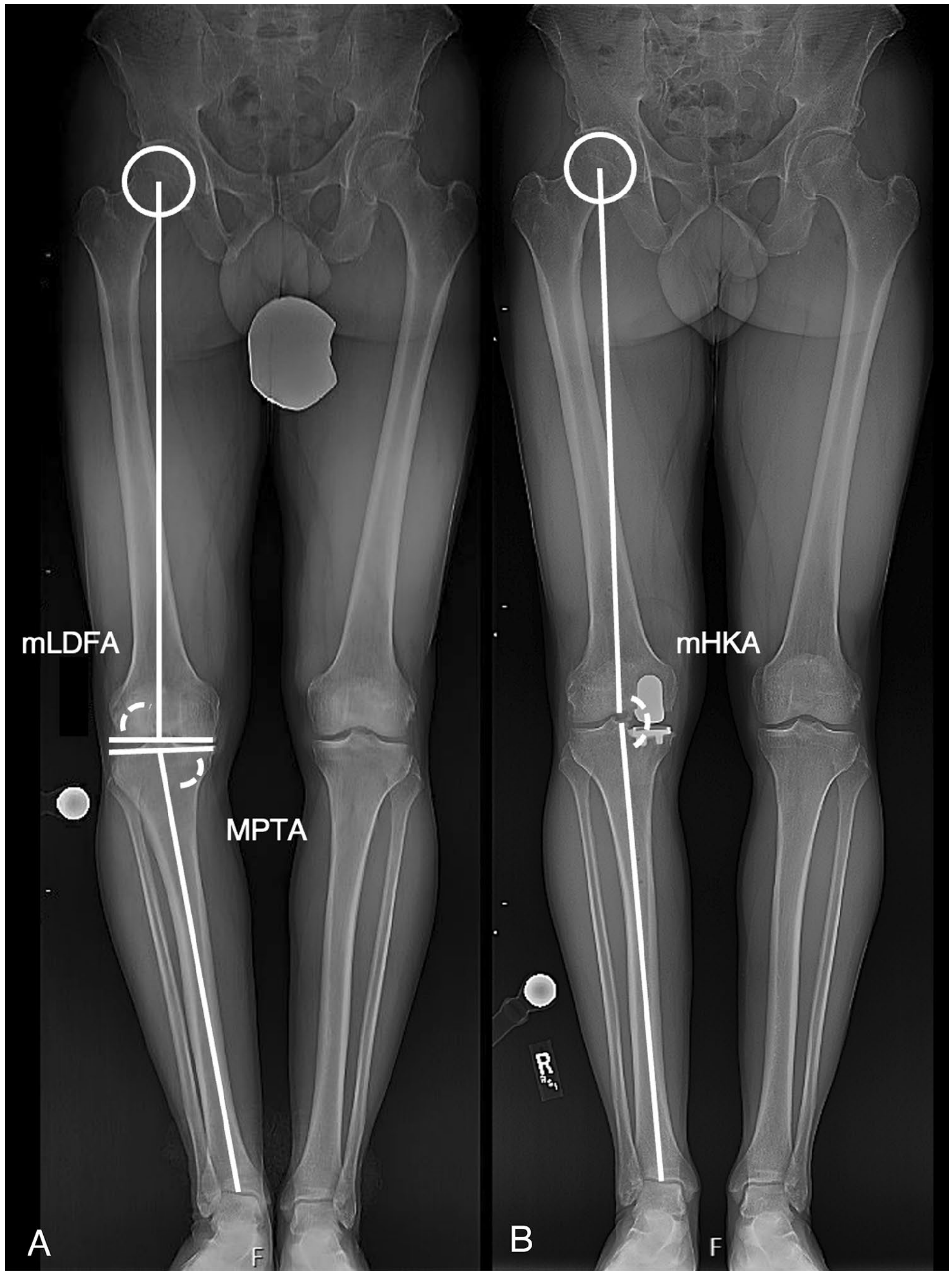

Fig. 2 **A** Preoperative long-leg radiograph. The mechanical lateral distal femoral angle (mLDFA) was defined as the lateral angle formed by the femoral mechanical axis and the joint line of the distal femur. The medial proximal tibial angle (MPTA) was defined as the medial angle formed by the tibial mechanical axis and the joint line of the proximal tibia. The femoral mechanical axis was drawn from the center of the femoral head to the center of the femoral condyles. The tibial mechanical axis was drawn from the center of the tibial plafond to the intercondylar eminence. **B** Postoperative long-leg radiograph following robotic-arm assisted medial unicompartmental knee arthroplasty. The mechanical hip-knee-ankle angle (mHKA) was defined as the intersection of the femoral and tibial mechanical axes

Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores [17, 20] at the latest follow-up (range 2.0–9.8 years) were collected. To increase power, WOMAC scores were converted to KOOS, JR, using validated crosswalks [10]. Additional outcomes included satisfaction with the overall function of the operative knee (i.e., "very satisfied", "satisfied", "neutral", "dissatisfied", or "very dissatisfied"), and whether or not patients would opt to undergo the surgery again.

Patient acceptable symptom state

To characterize satisfactory outcomes, patient-acceptable symptom state (PASS) thresholds for KOOS, JR and Kujala were defined using an anchor-based method. Patients who rated their outcome as very satisfied or satisfied were grouped as "satisfied" to create an anchor. Receiver operating characteristic (ROC) curve analyses were conducted to determine the PASS threshold that best discriminated

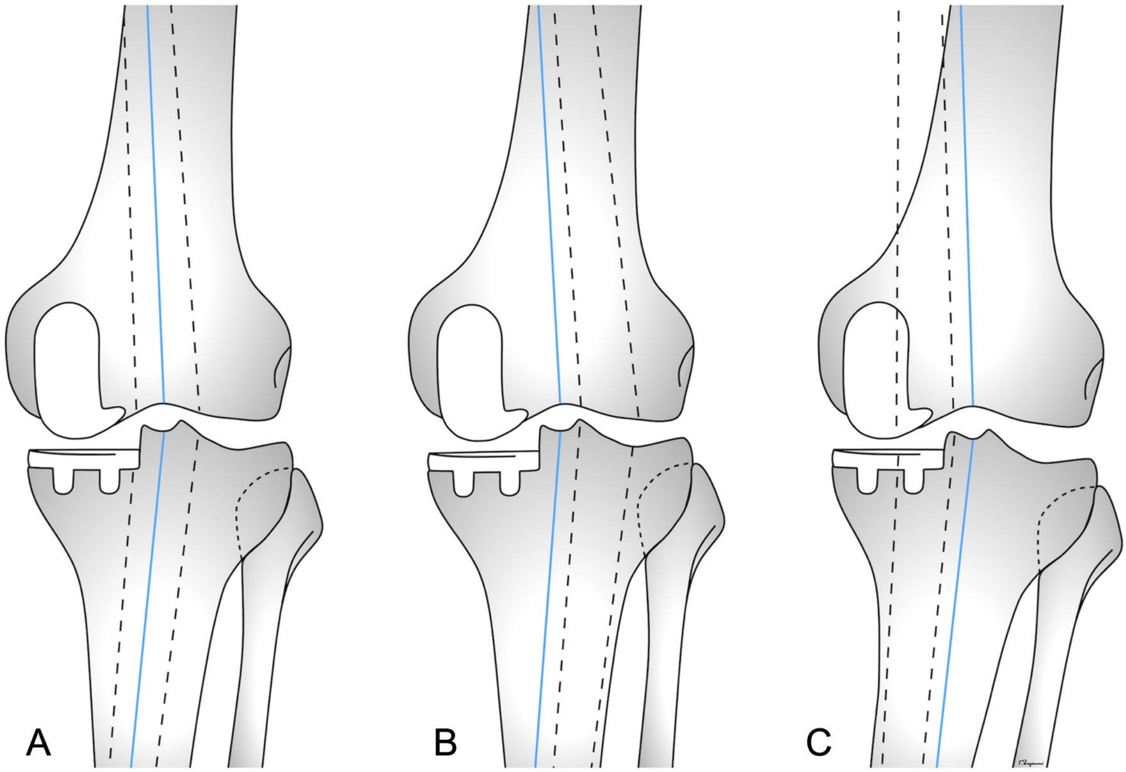

Fig. 3 Alignment categories of pre-arthritically and non-pre-arthritically aligned knees following medial unicompartmental knee arthroplasty. The continuous blue line represents the measured postoperative mechanical hip-knee-ankle angle (mHKA). The dashed lines represent the margins of + 2.0° and − 2.0° from the estimated pre-arthritic alignment, using the arithmetic hip-knee-ankle algorithm (aHKA) as an estimator for pre-arthritic alignment. **A** A pre-arthritically aligned knee (Group 1) with a postoperative mHKA within the margins of ± 2.0° from the pre-arthritic alignment. **B** A non-pre-arthritically aligned knee with a postoperative mHKA with > 2.0° of overcorrection from the pre-arthritic alignment (Group 2). **C** A non-pre-arthritically aligned knee with a postoperative mHKA with > 2.0° of under correction from the pre-arthritic alignment (Group 3)

between satisfied and non-satisfied patients. The optimal threshold was identified as the coordinate at which the combination of sensitivity and specificity was maximized (i.e., Youden Index) [35].

Statistical analysis

Data were tested for normal distribution using the Shapiro–Wilks test. Normally distributed data were compared between groups using one-way analysis of variance (ANOVA). Comparison of nonparametric data was carried out using the Kruskal–Wallis test, with post hoc pairwise comparison using the Mann–Whitney *U* test. Discrete variables were compared using Chi-Square tests. Overall implant survivorship was analyzed using the Kaplan–Meier method, with conversion to TKA as the endpoint. Implant survivorship was compared between groups using the log-rank test. Multivariable regression analysis was used to assess differences in PROMs between groups while adjusting for age, body mass index (BMI), gender, and postoperative alignment. Sample size calculations were conducted using G*Power [9]. 32 pre-arthritically aligned knees and 16 non-pre-arthritically aligned knees were needed to show a minimal clinically important difference (MCID) of 14 points in the KOOS, JR [21], using a standard deviation of 15.9 points [5], enrollment ratio of 2:1, alpha of 0.05, and power of 80%. For Kujala, 57 pre-arthritically aligned knees and 29 non-pre-arthritically aligned knees were needed to demonstrate an MCID of 10 points [33], using a standard deviation of 15.1 [4]. All other analyses were conducted using SPSS version 25.0 (IBM, Armonk, NY, USA) with the significance level set at 0.05.

Results

Restoration of pre-arthritic alignment

A total of 369 knees (69%) were pre-arthritically aligned (i.e., restored within ± 2.0° of their pre-arthritic alignment; Group 1). A total of 107 knees (20%) had a postoperative mHKA with > 2.0° of overcorrection from their pre-arthritic alignment (Group 2), and 61 knees (11%) had a postoperative mHKA with > 2.0° of under correction from their pre-arthritic alignment (Group 3). Demographics per group are presented in Table 2.

Patient-reported outcomes

At a mean follow-up of 4.4 ± 1.6 years, no significant differences were observed between groups in KOOS, JR (Table 3). In contrast, the mean Kujala score was significantly lower in Group 3 compared to Group 1 and Group 2 (Table 3). Multivariable analysis demonstrated that Group 3 was a predictor for a lower Kujala score, independent of age, BMI, gender and postoperative mHKA ($\beta = -7.3$, [95% CI − 12.0 to − 2.6]; $p = .003$). Furthermore, no significant differences were observed when comparing mean scores of knees with a postoperative mHKA between 0° and 4° of varus, to those with a postoperative mHKA of > 4° of varus (KOOS, JR: 85.1 ± 15.8 vs. 82.8 ± 16.9, respectively; n.s.; Kujala: 84.1 ± 14.5 vs. 81.6 ± 17.0, respectively; n.s.).

Patient acceptable symptom state

ROC analysis demonstrated a PASS threshold for KOOS, JR of 72.0 points (area under the curve [AUC] 0.91). The PASS threshold for Kujala was 76.5 points (AUC 0.90). No significant differences between groups were observed in the proportions of knees that achieved the KOOS, JR PASS. The proportion of knees that achieved the Kujala PASS was significantly lower in Group 3 compared to Group 1 (Table 3).

Implant survivorship

5-year implant survivorship in Group 1 was significantly higher than in Group 3 (98.6% vs. 90.5%, respectively; $p = .04$) (Fig. 4). Implant survivorship was similar between Groups 1 and 2 (98.6% and 100%, respectively; *n.s.*).

Patient satisfaction

Satisfaction rates were comparable among groups (Table 4). Similarly, most patients in each group reported that they would choose to undergo the surgery again, with no significant differences between groups.

Discussion

The most important finding of this study was that pre-arthritically aligned knees and knees with a relative overcorrection in relation to their pre-arthritic alignment demonstrated improved mid-term outcomes and survivorship following

Table 2 Demographics and radiographic outcomes by alignment group

Variable	Pre-arthritically aligned	Non-pre-arthritically aligned		p value
	Group 1	Group 2	Group 3	
	(Within 2.0° of pre-arthritic alignment)	(> 2.0° of overcorrection from the pre-arthritic alignment)	(> 2.0° of under correction from the pre-arthritic alignment)	
No. knees	369	107	61	
Demographics				
Age (year)	63.4 ± 8.9 (42.2 to 86.8)	63.4 ± 10.3 (41.4 to 86.2)	61.9 ± 7.6 (43.5 to 81.4)	n.s.†
BMI (kg/m²)§	29.3 ± 5.0 (17.5 to 45.7)	28.7 ± 4.5 (19.8 to 44.5)	32.2 ± 6.5 (18.3 to 46.0)	< .001†*
Gender (male)	206 (55.8%)	72 (67.3%)	32 (52.5%)	n.s.‡
Radiographic outcomes				
Preoperative mHKA	7.5° ± 3.1° (− 0.2 to 17.9)	9.7° ± 3.2° (3.5 to 17.9)	7.2° ± 2.3° (2.7 to 12.5)	< .001†*
Postoperative mHKA	3.0° ± 2.1° (− 2.0 to 9.4)	2.2° ± 2.3° (− 3.1 to 8.9)	5.1° ± 1.9° (1.8 to 10.6)	< .001†*
MPTA	85.7° ± 1.9° (79.9 to 91.0)	84.0° ± 2.1° (78.8 to 88.0)	86.4° ± 2.0° (81.2 to 91.6)	< .001†*
mLDFA	88.7° ± 1.9° (83.1 to 95.3)	89.6° ± 2.2° (83.4 to 95.4)	88.3° ± 1.9° (83.4 to 93.6)	< .001†*
aHKA	3.0° ± 2.1° (− 0.4 to 9.4)	5.6° ± 2.4° (1.0 to 11.6)	1.9° ± 1.6° (− 0.4 to 6.0)	< .001†*

Demographics and radiographic outcomes are presented per alignment group and are given as mean ± standard deviation (SD) with the range in parentheses, or in numbers with the frequency in parentheses

aHKA arithmetic hip-knee-ankle angle, *BMI* body mass index, *mLDFA* mechanical lateral distal femoral angle, *mHKA* mechanical hip-knee-ankle angle, *MPTA* medial proximal tibial angle, *n.s.* not significant

§BMI was missing for 51 knees

†Analysis of variance (ANOVA) test

‡Chi-square test

*Significant value

Table 3 Patient-reported outcomes by alignment group

Variable	Total	Pre-arthritically aligned	Non-pre-arthritically aligned		p value across groups	Post hoc pairwise comparison§		
		Group 1	Group 2	Group 3				
		(Within 2.0° of pre-arthritic alignment)	(> 2.0° of over-correction from the pre-arthritic alignment)	(> 2.0° of under-correction from the pre-arthritic alignment)		Comparison	Mean difference	p value
KOOS, JR								
No. knees	535	368	107	60				
Mean ± SD	84.5 ± 16.0	84.7 ± 16.2	84.7 ± 14.7	83.2 ± 16.9	n.s.†	G1 vs. G2	0.01	n.s
Range	(0.0–100.0)	(0.0–100.0)	(47.5–100.0)	(36.9–100.0)		G1 vs. G3	1.51	n.s
						G2 vs. G3	1.49	n.s
Achieved PASS (72.0 points)	421 (78.7%)	291 (79.1%)	86 (80.4%)	44 (72.1%)	n.s.‡	G1 vs. G2		n.s
						G1 vs. G3		n.s
						G2 vs. G3		n.s
Achieved maximum score (100 points)	184 (34.4%)	129 (35.1%)	36 (33.6%)	19 (31.7%)	n.s.‡	G1 vs. G2		n.s
						G1 vs. G3		n.s
						G2 vs. G3		n.s
Kujala								
No. knees	509	351	104	54				
Mean ± SD	83.5 ± 15.1	84.1 ± 14.8	85.1 ± 14.2	76.0 ± 17.1	.001†*	G1 vs. G2	− 0.97	n.s
Range	(23.0–100.0)	(23.0–100.0)	(49.0–100.0)	(30.0–100.0)		G1 vs. G3	8.14	.002*
						G2 vs. G3	9.11	.003*
Achieved PASS (76.5 points)	368 (72.3%)	260 (74.1%)	76 (73.1%)	32 (59.3%)	n.s.‡	G1 vs. G2		n.s
						G1 vs. G3		.02*
						G2 vs. G3		n.s
Achieved maximum score (100 points)	79 (15.5%)	56 (16.0%)	18 (17.3%)	5 (9.3%)	n.s.‡	G1 vs. G2		n.s
						G1 vs. G3		n.s
						G2 vs. G3		n.s

Patient-reported outcomes are reported by alignment group and are given as the mean ± standard deviation (SD) with the range in parentheses, or in numbers with the frequency in parentheses

KOOS, JR Knee Injury and Osteoarthritis Outcome Score for Joint Replacement, *n.s.* not significant, *PASS* patient acceptable symptom state

†Kruskal-Wallis test

‡Chi-square test

§Post hoc pairwise comparison using the Mann-Whitney U test or Chi-square test

*Significant value

robotic-assisted medial UKA, compared to knees with relative undercorrection from their pre-arthritic alignment. The current observations suggest that favorable outcomes can be achieved when coronal alignment in medial UKA is individualized with the aim to restore pre-arthritic alignment, even if the final alignment is slightly overcorrected in relation to the pre-arthritic alignment. However, based on these findings, surgeons should aim to avoid under correction in relation to the pre-arthritic alignment, as this may lead to suboptimal outcomes. Nevertheless, it is important to emphasize that in this context, the terms "over-" and "under correction" refer to over- and undercorrection of alignment relative to the patient's individual pre-arthritic alignment and not in relation to a neutral mechanical axis.

In recent decades, it has become clear that a patient's native alignment is often not neutral [3, 14], and application of a systematic alignment approach for UKA, without consideration of the constitutional status of the knee, may impose significant alterations in anatomy and postoperative kinematics [14]. Contemporary alignment strategies, therefore, focus on recreating the individual pre-arthritic alignment to optimize functionality and survivorship of the

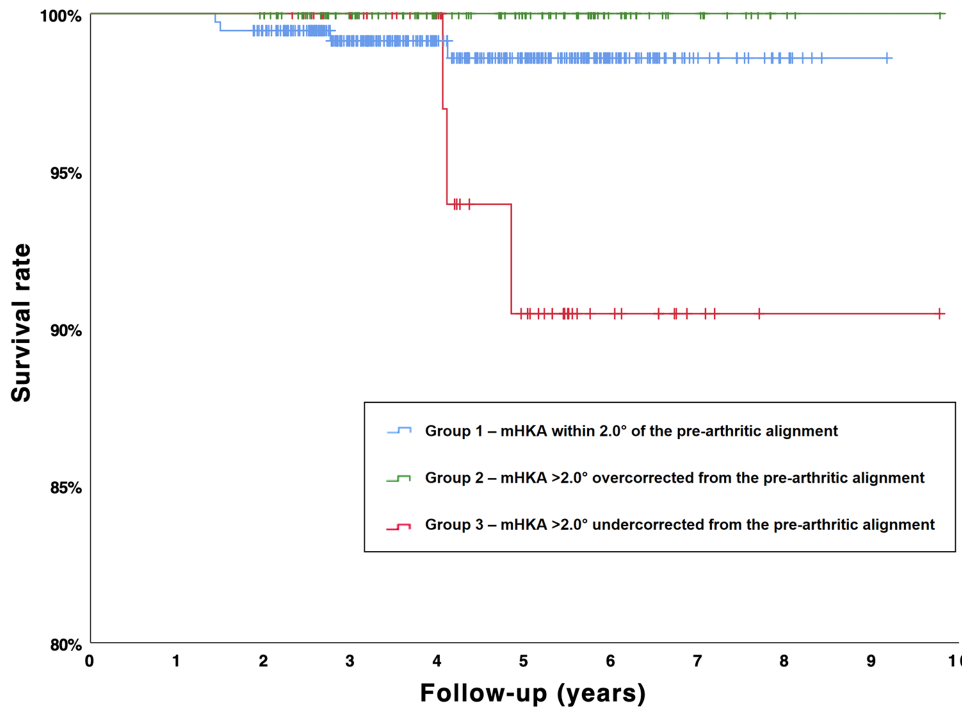

Fig. 4 Kaplan Meier Curve of robotic-arm assisted medial unicompartmental knee arthroplasty for Group 1 ($n = 369$), Group 2 ($n = 107$) and Group 3 ($n = 61$), with revision to total knee arthroplasty as the endpoint. *mHKA* mechanical hip-knee-ankle angle

Table 4 Patient satisfaction by alignment group

	Pre-arthritically aligned	Non-pre-arthritically aligned		*p* value across groups
	Group 1	Group 2	Group 3	
	(Within 2.0° of pre-arthritic alignment)	(> 2.0° of overcorrection from the pre-arthritic alignment)	(> 2.0° of undercorrection from the pre-arthritic alignment)	
Total no. of knees[‡]	352	104	55	
Satisfaction, *n* (%)				
Satisfied	323 (91.8%)	94 (90.4%)	50 (90.9%)	n.s.[†]
Neutral	15 (4.3%)	5 (4.8%)	1 (1.8%)	
Dissatisfied	14 (4.0%)	5 (4.8%)	4 (7.3%)	
Undergo surgery again, *n* (%)				
Yes	329 (93.5%)	96 (92.3%)	50 (90.9%)	n.s.[†]
No	23 (6.5%)	8 (7.7%)	4 (7.3%)	

Distribution op patients' satisfaction with the overall function of the operative knee is given in numbers and frequencies. "Satisfied" refers to patients who reported to be either very satisfied or satisfied. "Dissatisfied" refers to patients who are reported to be either dissatisfied or very dissatisfied

n.s. not significant

[‡]Revised knees were not included in this analysis

[†]Chi-square test

prosthesis [25, 28]. These concepts address the broad variability in the anatomy of the individual knee and therefore allow for deviation from the generally considered "normal" neutral alignment. The application of an individualized alignment approach, guided by re-tensioning of the MCL, has been shown to restore both joint line obliquity and the mechanical axis to its pre-arthritic state following medial UKA for medial compartment OA [1]. Theoretically, restoration of the natural soft tissue envelope and knee kinematics may translate into reduced postoperative stiffness, better load distribution, and subsequently improved functional outcomes and survivorship [23, 27, 36]. However, supportive evidence on the clinical relevance of a pre-arthritic alignment strategy remained scarce.

Plancher et al. [25] recently compared 127 pre-arthritically aligned knees (within 3.0° of their aHKA) to 23 non-pre-arthritically aligned knees following medial UKA, and found improved long-term patient-reported outcomes and survivorship of knees that were restored to their pre-arthritic alignment. Similar to the study by Plancher et al. [25], the present study found favorable results following the restoration of pre-arthritic alignment in patients that underwent UKA for medial compartment OA. Nonetheless, instead of a single comparison between pre-arthritically and non-pre-arthritically aligned knees, the current study aimed to further categorize non-pre-arthritically aligned knees into two groups, based on the direction of deviation from their pre-arthritic alignment. Not only did this analysis demonstrate that the two non-pre-arthritically aligned groups differed substantially in preoperative coronal alignment parameters (Table 2), but more importantly, showed clinically relevant differences in outcomes between these groups.

Interestingly, knees with a relative overcorrection from their pre-arthritic alignment in Group 2 demonstrated favorable outcomes and excellent 5-year survivorship, similar to pre-arthritically aligned knees in Group 1. However, from the present study it cannot be concluded whether the favorable results in Group 2 were derived from a biomechanically advantageous implant position and alignment or were the result of a seemingly enlarged aHKA (e.g., due to extra-articular deformities such as a reduced MPTA; Table 2). Furthermore, it is currently not known to what degree overcorrection from the pre-arthritic alignment can be accepted without imposing the risk of clinical deterioration. To reduce the risk of lateral compartment degeneration, the surgical technique in the present study was restricted by neutral alignment [12, 37]. Similarly, although the current observations discourage $>2.0°$ of under correction relative to the pre-arthritic alignment, it remains unclear what degree of postoperative varus is acceptable when aiming to restore pre-arthritic alignment. No significant deterioration of functional outcomes was observed with increased postoperative varus alignment in the present study; however, future studies are needed to further define these boundaries.

It is interesting to note that a significantly lower mean Kujala score was found in Group 3 while KOOS, JR outcomes were similar between groups. Additionally, the proportion of knees that achieved the Kujala PASS was substantially lower in Group 3 compared to Group 1, whereas these differences were not observed with respect to the KOOS, JR PASS. In contrast to the KOOS, JR, the Kujala is a patellofemoral-specific scoring system [17]. The inferior Kujala scores in Group 3 may therefore specifically indicate the presence of anterior knee/patellofemoral pain in this group. Medial UKA has been shown to improve patellofemoral congruence and, potentially, optimize contact forces across the joint [32]. However, from a mechanistic perspective, it could be suggested that a larger postoperative varus deformity in Group 3 (Table 2) led to, or maintained disrupted patellofemoral congruence with suboptimal patellar tracking and increased stress across the patellofemoral joint [8]. Nevertheless, another explanation for the discrepancy in outcomes between these PROMs may be found in the ceiling effect of the KOOS, JR, with over 30% of knees in all groups achieving the maximum score (Table 3). The large ceiling effect in this score may have limited further differences among groups from being identified [31]. In contrast, with regard to Kujala, the ceiling effect was well under 20% in Groups 1 and 2, and under 10% in Group 3. Hence, due to the smaller ceiling effect, Kujala may have been a more sensitive score to detect differences in functional outcome in this cohort.

The present study demonstrates that alignment within respective margins of the pre-arthritic alignment may result in superior postoperative outcomes compared to alignment outside those margins. Hence, the precision of component positioning is likely to factor into the final outcome of the procedure. The precision of the robotic system used in the present study has been well described [6, 7, 26], and allows for accurate ligament balancing, component positioning and lower leg alignment with respect to the surgical plan. Moreover, a recent systematic meta-analyses overview demonstrated that robotic-assisted systems facilitated more accurate component placement within target zones compared to conventional techniques [16]. Therefore, the question remains to what extent the current findings are applicable to conventional UKA procedures, as targets for soft tissue balance and subsequent alignment may be harder to achieve without robotic assistance. In addition, it should be considered that the precision of surgical variables may be specific to certain robotic platforms and may therefore differ per manufacturer.

The present study recognizes several limitations. The first derives from the retrospective study design, which may have introduced selection bias. Secondly, differences in demographics and radiographic outcomes, such as BMI and pre- and postoperative alignment, were present among groups which may have had a confounding effect on outcomes. Nevertheless, the study aimed to correct for these potential confounders in PROM-evaluation by conducting multivariable analysis, which demonstrated similar results after adjustment for those factors. Third, this study involved a fixed-bearing UKA system and due to different biomechanical properties, these results may not be applicable to mobile-bearing designs. Fourth, no direct comparison with other alignment strategies was performed. Fifth, this study was limited to an assessment of restoration of pre-arthritic mechanical alignment only. Given the variability of knee phenotypes (i.e., femoral and tibial joint line orientation) that can occur in combination with mechanical alignment phenotypes, future studies should consider including these factors and assess their influence on clinical outcomes following medial UKA.

Conclusion

Pre-arthritically aligned knees and knees with relative overcorrection from their pre-arthritic alignment following medial UKA demonstrated improved mid-term outcomes and survivorship compared to knees with relative under correction from their pre-arthritic alignment. These results encourage restoring or relatively overcorrecting pre-arthritic alignment to optimize outcomes following medial UKA, and caution against under correction from the pre-arthritic alignment.

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Data availability The dataset used and analyzed for the current study can only be made available upon reasonable request through the corresponding author.

Declarations

Conflict of interest Dr. Andrew D. Pearle is a consultant for Smith & Nephew and DePuy Synthes. Dr. Hendrik A. Zuiderbaan is a consultant for Smith & Nephew. The other authors declare to have no potential conflict of interest.

Ethical approval Approval from the Internal Review Board of the Hospital for Special Surgery was obtained prior to the start of the study (IRB #2021-2004).

Informed consent Informed consent was not applicable to this study.

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