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# Robotic-assisted medial unicompartmental knee arthroplasty restores estimated pre-arthritic coronal limb alignment: A retrospective cohort study

Tarik Bayoumi [a,*], Joost A. Burger [b], Hendrik A. Zuiderbaan [c], Lindsey V. Ruderman [a], Joseph T. Nguyen [d], Andrew D. Pearle [a]

[a] Department of Orthopedic Surgery, Computer Assisted Surgery and Sports Medicine, Hospital for Special Surgery, Weill Medical College of Cornell University, New York, NY, USA
[b] Charité – Universitätsmedizin Berlin, Corporate Member of Freie Universität Berlin and Humboldt Universität, Berlin, Germany
[c] Department of Orthopedic Surgery, Medische Kliniek Velsen, Velsen, The Netherlands
[d] Biostatistics Core, Healthcare Research Institute, Hospital for Special Surgery, New York, USA

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ABSTRACT

*Background:* Robotic-assisted medial unicompartmental knee arthroplasty (UKA) aims to restore pre-arthritic (constitutional) limb alignment, by re-tensioning of the medial collateral ligament (MCL). This study aimed to determine whether pre-arthritic coronal alignment was restored following robotic-assisted medial UKA in patients with medial compartment osteoarthritis.
*Method:* A retrospective study was undertaken, including 102 patients with a unilateral robotic-assisted medial UKA and a contralateral unaffected knee. Both the validated arithmetic hip-knee-ankle angle (aHKA) and alignment of the contralateral unaffected knee were used to estimate pre-arthritic alignment. The aHKA is a radiographic method to estimate the pre-arthritic mechanical hip-knee-ankle angle (mHKA). To verify restoration of pre-arthritic alignment, postoperative mHKA was compared to the aHKA. Additionally, postoperative mHKA, joint line congruence (JLCA), and knee joint line obliquity (KJLO) angles were compared between the operative and contralateral unaffected knee. Equivalence between postoperative and pre-arthritic alignment was assessed through the two-one-sided t-test (TOST), using equivalence margins of ±2.0°.
*Results:* Postoperative mHKA was equivalent to the aHKA (mean difference −0.38°, 90% CI −0.69 to −0.07; $p < .001$), with 93 knees (91%) restored within 3.0° their aHKA. Postoperative mHKA, JLCA and KJLO were equivalent between the operative and contralateral unaffected knees, with mean differences of −0.65°, −0.65°, and −0.40°, respectively; all $p < .001$.
*Conclusions:* Postoperative and pre-arthritic coronal alignment were equivalent following robotic-assisted medial UKA, with 91% of knees restored within 3.0° of their pre-arthritic mechanical axis. These results demonstrate that both mechanical alignment and joint line congruence are restored by MCL re-tensioning in patients undergoing robotic-assisted medial UKA for medial compartment osteoarthritis.



* Corresponding author at: 535 East 70th Street, New York, NY 10021, USA.
*E-mail address:* bayoumit@hss.edu (T. Bayoumi).

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## 1. Introduction

Medial unicompartmental knee arthroplasty (UKA) is an effective treatment for isolated medial osteoarthritis (OA) [1,2]. A recognized key factor for successful outcome following medial UKA is coronal limb alignment [3,4]. However, controversy exists on the optimal alignment strategy for medial UKA and alignment target recommendations vary from near-neutral to varus alignment [5–8].

More recent strategies aim to address the variability in individual anatomy [9,10] and attempt to recreate a patient's native knee kinematics and alignment before onset of OA (i.e., pre-arthritic alignment) [6,11–13]. The clinical relevance of such a pre-arthritic alignment strategy has recently been demonstrated by Plancher et al. [14], who reported improved long-term functional outcomes and implant survivorship of knees restored to their pre-arthritically alignment compared to non-pre-arthritically aligned knees following medial UKA.

Robotic systems for UKA allow surgeons to use a so-called ligament-guided technique to restore pre-arthritic alignment. In this technique, correction in coronal alignment is dictated by re-tensioning of the medial collateral ligament (MCL) through optimization of implant size and position [15,16]. Robotic systems provide visual, real-time tension-gap estimates throughout the range of motion (ROM) [15] while valgus stress is applied to correct the knee to its pre-arthritic alignment [17]. The intraoperative visual feedback enables surgeons to precisely assess and optimize ligament tension throughout the ROM before any bony cut is made [16]. In contrast, during conventional techniques, ligament balance is often manually assessed after the bony cuts with the trial components in place, using feeler gauges.

Although surgical precision of robotic systems for UKA has been well-established [12,18], and the general assumption is that UKA recreates the pre-disease alignment, evidence on its ability to restore pre-arthritic alignment is lacking. The purpose of this study was to assess whether robotic-assisted medial UKA restores pre-arthritic coronal alignment in patients with medial compartment OA. We hypothesized that postoperative coronal alignment would be equivalent to estimated pre-arthritic alignment following this procedure.

## 2. Methods

### 2.1. Study design

Following Institutional Review Board approval (IRB #2021-0583), records from a single surgeon's database (ADP) were retrospectively reviewed. All patients treated with robotic-assisted medial UKA for symptomatic medial OA between January 2015 and February 2020 were assessed for study eligibility. Patients with medial OA that underwent robotic-assisted medial UKA were included if they had a radiologically (Kellgren-Lawrence [KL] grade $\leq 2$) [19] unaffected contralateral knee. The study exclusion criteria are listed in Figure 1. The surgeon's ligament-guided technique for medial UKA was restricted by neutral alignment to avoid overcorrection in valgus with the potential risk of lateral compartment degeneration [3,20]. In

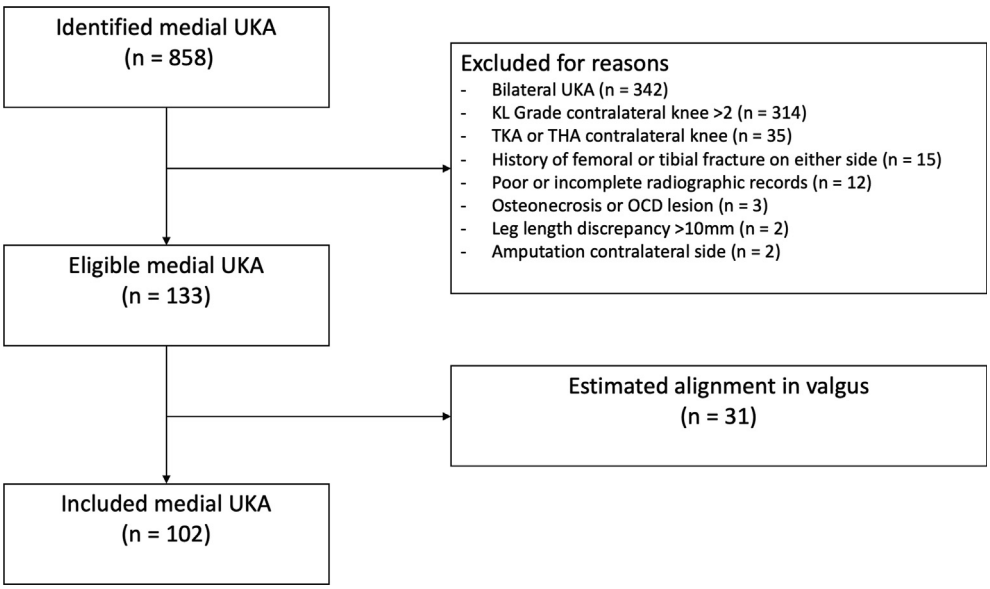


**Figure 1.** Flowchart of the inclusion and exclusion of patients and reasons for exclusion. *KL grade*, Kellgren-Lawrence grade [19]; *OCD*, osteochondritis dissecans; *THA*, total hip arthroplasty; *TKA*, total knee arthroplasty, *UKA*, unicompartmental knee arthroplasty.

other words, these knees were corrected to a neutral mechanical axis instead of to their pre-arthritic alignment. Hence, patients with an estimated pre-arthritic alignment in valgus ($\leq -0.5°$) were per definition not restored to their estimated pre-arthritic alignment, and were therefore excluded from this study.

The primary indication for medial UKA was end-stage symptomatic medial OA (KL grade 3–4 on anteroposterior weight-bearing views) with a varus deformity that was passively correctable to <10°, with an intact MCL, and a fixed flexion deformity of <10°. Correctability of the varus deformity was tested with the knee in 30° of flexion during physical examination. Patients were non-eligible for UKA if they had significant clinical or radiological signs of contralateral compartment OA (KL grade >2), signs of inflammatory arthritis, lateral patellar facet KL grade 4 changes, or prior MCL surgery. Anterior cruciate ligament (ACL) deficiency in the absence of clinical instability, prior ACL reconstruction, weight or body mass index (BMI) were not considered contraindications for medial UKA.

### 2.2. Implant and surgical technique

All patients received a cemented fixed-bearing medial UKA (Restoris MCK System, Mako Surgical Corp. (Stryker), Fort Lauderdale, FL, USA). All procedures were performed by one surgeon (ADP) according to a previously described technique, using a robotic-assisted system (Mako Surgical Corp. (Stryker), Fort. Lauderdale, FL, USA) [15,16]. In brief, preoperative planning of femoral and tibial component size and position was performed using a computed tomography (CT) scan-based 3D model. Intraoperatively, the patient's knee anatomy and long leg alignment were registered to the 3D model, allowing real-time visual feedback. Following kinematic analysis under valgus stress to identify MCL tension gaps, virtual components were optimized to properly tension the MCL throughout the ROM. The tibial component was planned to be in 5–7° of posterior slope and 2° of varus to optimize kinematics [21]. Subsequently, the femur was planned to center over the tibia during ROM [22] and balance flexion and extension gaps, pursuing a 1–2 mm medial gap under valgus stress. Corresponding bone resection areas and cutting boundaries were automatically generated and displayed by the robotic system. Once the surgical plan was finalized, a robotic-arm with a 6 mm burr was used for preparation of the bone. Neutral alignment was pursued if, based on MCL tension, a patient's native alignment was estimated as valgus. The knee was considered well-balanced if, after placement of the polyethylene insert, a stability test under valgus stress with the knee in 30° of flexion would demonstrate a 1–2 mm medial gap. Soft tissue releases to balance the knee were strictly avoided.

### 2.3. Radiographic evaluation

All radiographic measurements for this study were retrospectively performed on routine preoperative and six-week postoperative weight-bearing long-leg radiographs. When obtaining these radiographs, patients were instructed to stand with their feet as close together as possible while having their knees fully extended, their bodyweight evenly distributed over both limbs, and their patellae orientated forward, aligned with the X-ray beam.

All radiographic measurements were performed independently by two research fellows (JAB & TB) in a Picture Archiving and Communication System (PACS, Sectra Imtec AB, version 16, Linköping, Sweden). Intraclass correlation coefficients (ICC) were used to evaluate inter-observer reliability, using a two-way mixed model with absolute agreement. ICC was good-to-excellent for all measurements (range, 0.77 [95% confidence interval (CI) 0.69 to 0.83] to 0.94 [95% CI 0.91 to 0.96]) [23].

### 2.4. Estimation of pre-arthritic alignment

For each patient, the validated arithmetic hip-knee-ankle (aHKA) algorithm [24] was used as primary method to estimate pre-arthritic alignment, and the contralateral unaffected knee was used as a secondary estimator. We included parameters to assess pre-arthritic mechanical alignment, joint line congruence and obliquity, femoral and tibial alignment, and the position of the weight-bearing axis (WBA).

#### 2.4.1. Pre-arthritic mechanical alignment and aHKA algorithm

The aHKA estimates the pre-arthritic mechanical hip-knee-ankle angle (mHKA, i.e., the mechanical axis) using preoperative radiographs of the operative knee [24]. The aHKA was determined by subtracting the mechanical lateral distal femoral angle (mLDFA) from the medial proximal tibial angle (MPTA) (Figure 2A). Postoperative mHKA of the operative knee was defined as the angle between the femoral mechanical axis (center of femoral head to femoral intercondylar point) and the tibial mechanical axis (tibial interspinous point to center of tibia plafond) (Figure 2B). To assess whether the mechanical axis was restored after medial UKA, the pre-arthritic mechanical axis (aHKA) was compared to the postoperative mechanical axis (mHKA).

#### 2.4.2. Pre-arthritic mechanical alignment and the contralateral unaffected knee

The contralateral unaffected knee was used as a second method to estimate the pre-arthritic status of the operative knee, based on the assumption of symmetry between both limbs prior to onset of OA. Postoperative mHKA of the operative knee was compared to the mHKA of the contralateral unaffected knee (Figure 2B).

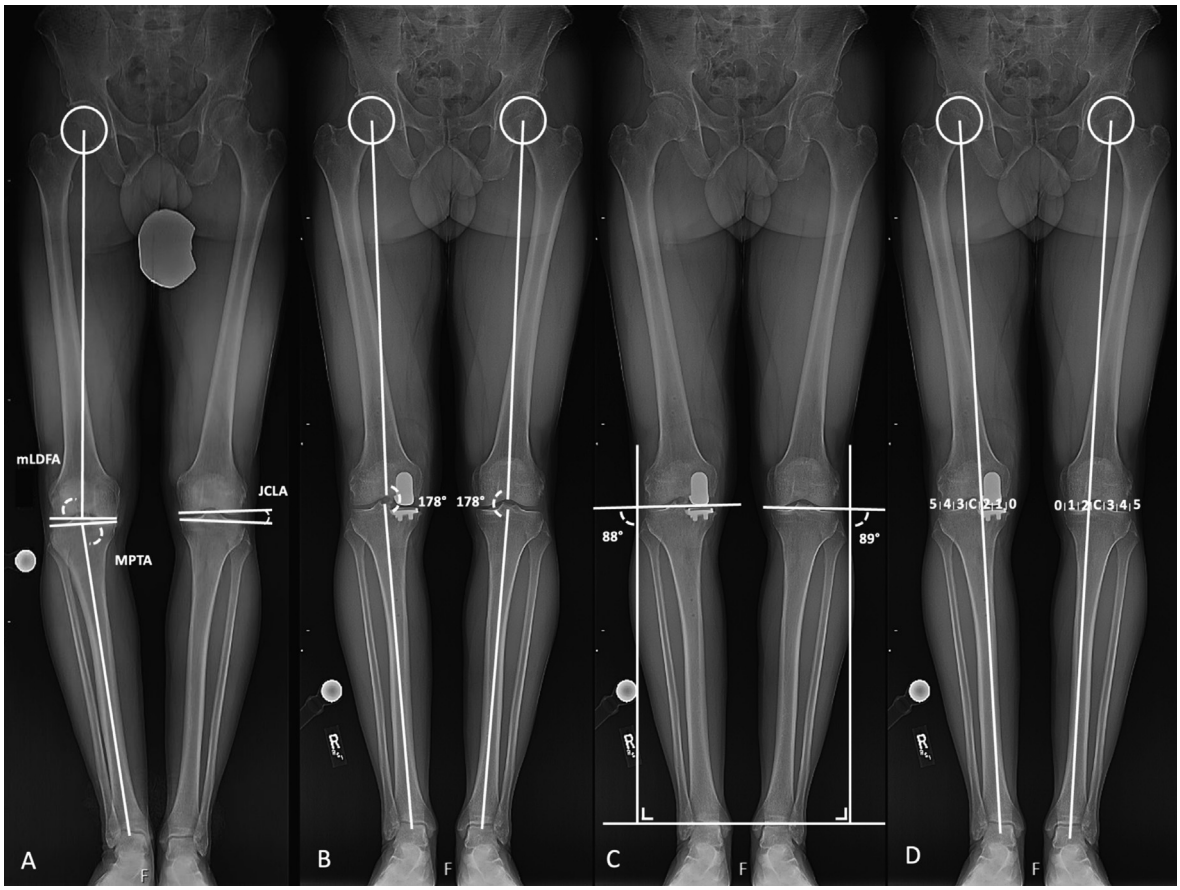


**Figure 2. A**, preoperative long-leg standing radiograph. **B-D**, postoperative long-leg standing radiograph following medial unicompartmental knee arthroplasty. **2A,** the mechanical lateral distal femoral angle (mLDFA) was defined as the lateral angle between the joint line of the distal femur and the mechanical femoral axis. The medial proximal tibial angle (MPTA) was formed by the medial angle between the joint line of the proximal tibia and the tibial mechanical axis. The joint line congruence angle (JLCA) was defined as the angle between the joint lines of the distal femur and proximal tibia. **2B**, the mechanical hip-knee-ankle angle (mHKA, i.e., mechanical axis) was measured as the angle between the mechanical axes of the femur and tibia. **2C**, the knee joint line obliquity (KJLO) angle was defined as the angle between the perpendicular of a baseline joining the centers of the tibial plafonds of both limbs and the knee joint line. The postoperative knee joint line of the operative knee was drawn as a tangent from the lowest point of the femoral component to the midpoint of the lateral joint space at level of the most prominent point of the lateral femoral condyle. The knee joint line of the contralateral unaffected knee was plotted as a line joining the midpoints of the medial and lateral joint space at the level of the most prominent femoral condylar points. Preoperative KJLO of the operative knee was determined in a same manner as for the contralateral unaffected knee. **2D**, Kennedy and White's tibial zones [26] (i.e., zone 0, 1, 2, C, 3, 4, or 5) were drawn at the level of the tibial plateau to determine the position of the weight-bearing axis (WBA). Zone C, the center of the tibia plateau, was defined by the borders of the lateral and medial eminences. The medial and lateral tibial plateau were equally divided into zone 1, 2, 3 and 4. Zone 0 and 5 defined the areas medially and laterally to the tibial plateau, respectively.

### *2.4.3. Pre-arthritic joint line congruence and obliquity and the contralateral unaffected knee*

The contralateral unaffected knee was used to estimate the pre-arthritic joint line congruence and obliquity. The joint line congruence angle (JLCA) was defined as the angle between the femoral and tibial joint line (Figure 2A), and was computed for both knees using previously defined methods [25]. The knee joint line obliquity (KJLO) angle [11] was measured as the angle between the perpendicular of a line connecting the tibial plafond centers of both limbs and the knee joint line of each respective knee (Figure 2C). Postoperative JLCA and KJLO were compared between the operative knee and contralateral unaffected knee.

### *2.4.4. Pre-arthritic femoral and tibial alignment and the contralateral unaffected knee*

Postoperative mLDFA and MPTA (Figure 2A) were compared between both knees.

### *2.4.5. Pre-arthritic position of the weight-bearing axis and the contralateral unaffected knee*

Position of the WBA at the tibial joint line was determined following Kennedy and White's method [26], which divides the tibia plateau into seven zones (0, 1, 2, C, 3, 4 and 5; Figure 2D). Zone C refers to the center of the tibia plateau and was defined by the borders of the lateral and medial eminences. The medial and lateral tibial plateau were equally divided into zone 1

and 2, and zone 3 and 4, respectively. Zone 0 and 5 were formed by the area medially and laterally to the tibial plateau, respectively. Postoperative position of the WBA was compared between both limbs.

### 2.5. Statistical analyses

Continuous variables were presented as mean with standard deviation (SD) and compared using independent *t*-tests. Categorical data were reported in numbers and frequencies. A two-one-sided *t*-test (TOST) for statistical equivalence of paired samples was performed to evaluate equivalence between postoperative alignment of the operative knee and estimated pre-arthritic alignment parameters [27]. The equivalence margins were set to ±2.0°, based on accuracy margins of the robotic system [12,15]. For this analysis, the $H_0$ hypothesis states that the mean difference between postoperative alignment and estimated pre-arthritic alignment is outside the preset equivalence margins, while the $H_1$ hypothesis states that the mean difference is within these margins. Both tests of the TOST (lower and upper limit) have to be significant to conclude equivalence [27]. The level of significance was set at 0.05. Analyses were performed in SPSS version 25 (IBM Corp., Armonk, NY, USA).

## 3. Results

A total of 102 patients met the inclusion criteria (Figure 1). The mean age was 58.4 ± 8.3 years, mean BMI was 28.5 kg/m$^2$, and 75% of patients were male. Table 1 displays an overview of pre- and postoperative alignment as well as estimated pre-arthritic alignment.

### 3.1. Mechanical alignment and aHKA algorithm

A total of 93 knees (91%) were restored within 3.0° of their pre-arthritic mechanical axis (i.e., aHKA), 77 knees (75%) within 2.0°, and 42 knees (41%) within 1.0°. To evaluate the pre- to postoperative change in mechanical axis (i.e., mHKA), the average preoperative mechanical axis was 6.6° ±2.7, which was corrected to an average postoperative mHKA of 2.5° ±2.0 (Table 1). The average pre- to postoperative correction in mHKA was 4.2° ±2.5. The mean pre-arthritic mechanical axis (i.e., aHKA) was estimated to be 2.9° ±2.0. According to the TOST for statistical equivalence, mean postoperative mHKA of the operative knees was equivalent to mean aHKA, with a mean difference of −0.38° (90% CI −0.69 to −0.07; $p < .001$) (Table 2; Figure 3).

### 3.2. Mechanical alignment and the contralateral unaffected knee

Egithy-one knees (79%) were restored within 3.0° of the mechanical axis of their contralateral unaffected knee, 59 knees (58%) within 2.0°, and 37 knees (36%) within 1.0°. Postoperatively, mean mHKA of the operative knees was equivalent to mean mHKA of the contralateral unaffected knees, with a mean difference −0.65° (90% CI −1.04 to −0.26; $p < .001$) (Table 2; Figure 3). A total of 40 operative knees (39%) had a postoperative mHKA of ≥3° of varus, and 62 operative knees (61%) were neutrally aligned (i.e., mHKA of 0° ±3), whereas 51 contralateral unaffected knees (50%) had a mHKA of ≥3° of varus, and 51 contralateral unaffected knees (50%) had neutral alignment (Table 3).

**Table 1**
Measured pre- and postoperative alignment of the operative knee and estimated pre-arthritic alignment parameters.

| | Mean | SD | Range | Mean | SD | Range |
|---|---|---|---|---|---|---|
| **Measured alignment operative knee** | **Preoperatively** | | | **Postoperatively** | | |
| mHKA | 6.6° | 2.7 | 0.3 – 13.8 | 2.5° | 2.0 | −2.2 – 10.1 |
| JLCA | −3.8° | 2.1 | −8.2 – 0.6 | −1.9° | 1.3 | −6.3 – 0.8 |
| KJLO | 91.0° | 2.2 | 85.2 – 96.5 | 90.2° | 2.0 | 83.8 – 95.7 |
| mLDFA | 88.2° | 1.8 | 84.8 – 92.7 | 86.9° | 1.9 | 83.2 – 91.8 |
| MPTA | 85.3° | 1.7 | 81.7 – 90.4 | 86.3° | 1.5 | 81.4 – 89.8 |
| **Estimated pre-arthritic alignment** | | | | | | |
| aHKA algorithm operative knee | 2.9° | 2.0 | −0.4 – 9.1 | – | – | – |
| mHKA contralateral unaffected knee | – | – | – | 3.1° | 2.1 | −0.3 – 10.0 |
| JLCA contralateral unaffected knee | – | – | – | −1.2° | 1.2 | −4.6 – 2.1 |
| KJLO contralateral unaffected knee | – | – | – | 90.6° | 2.0 | 86.4 – 96.3 |
| mLDFA contralateral unaffected knee | – | – | – | 88.1° | 1.7 | 84.3 – 92.8 |
| MPTA contralateral unaffected knee | – | – | – | 86.2° | 1.8 | 82.7 – 90.9 |

Means of pre- and postoperative alignment parameters of the operative knee following medial unicompartmental knee arthroplasty and estimated pre-arthritic alignment for these respective parameters are reported in degrees (°), and presented with corresponding standard deviation (SD) and range. *aHKA*, arithmetic hip-knee-ankle angle (i.e., pre-arthritic mechanical axis); *JLCA*, joint line congruence angle; *KJLO*, knee joint line obliquity angle; *mHKA*, mechanical hip-knee-ankle angle (i.e., mechanical axis); *mLDFA*, mechanical lateral distal femoral angle; *MPTA*, medial proximal tibial angle.

**Table 2**
Equivalence test for postoperative alignment of the operative knee and estimated pre-arthritic alignment.

| Parameter | Postoperative alignment operative knee Mean ± SD | Estimated pre-arthritic alignment Mean ± SD | Equivalence test | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | Mean Difference | SD | SE | 90% CI | *p*-value | Conclusion |
| **Pre-arthritic alignment estimated by the aHKA algorithm** | | | | | | | | |
| | Operative knee | aHKA | | | | | | |
| mHKA | 2.5° ± 2.0 | 2.9° ± 2.0 | −0.38° | 1.89 | 0.19 | −0.69 to −0.07 | < .001* | Equivalence |
| **Pre-arthritic alignment estimated by the contralateral unaffected knee** | | | | | | | | |
| | Operative knee | Contralateral unaffected knee | | | | | | |
| mHKA | 2.5° ± 2.0 | 3.1° ± 2.2 | −0.65° | 2.37 | 0.23 | −1.04 to −0.26 | < .001* | Equivalence |
| JLCA | −1.9° ± 1.3 | −1.2° ± 1.2 | −0.65° | 1.67 | 0.17 | −0.92 to −0.37 | < .001* | Equivalence |
| KJLO | 90.2° ± 2.0 | 90.6° ± 2.0 | −0.40° | 2.09 | 0.21 | −0.74 to −0.06 | < .001* | Equivalence |
| mLDFA | 86.9° ± 1.9 | 88.1° ± 1.7 | −1.27° | 1.84 | 0.18 | −1.57 to −0.96 | < .001* | Equivalence |
| MPTA | 86.3° ± 1.6 | 86.2° ± 2.5 | 0.03° | 1.87 | 0.19 | −0.27 to 0.34 | < .001* | Equivalence |

Equivalence test for postoperative alignment of the operative knee following medial unicompartmental knee arthroplasty and estimated pre-arthritic alignments parameters with the equivalence margins set at ± 2.0°. Alignment parameter values are reported in degrees (°). The reported *p*-value indicates the greater of the upper and lower bound from the two-one-sided *t*-test (TOST) for statistical equivalence. *aHKA*, arithmetic hip-knee-ankle angle (i.e., pre-arthritic mechanical axis); *CI*, confidence interval; *JLCA*, joint line congruence angle; *KJLO*, knee joint line obliquity angle; *mHKA*, mechanical hip-knee-ankle angle (i.e., mechanical axis); *mLDFA*, mechanical lateral distal femoral angle; *MPTA*, medial proximal tibial angle; *SD*, standard deviation; *SE*, standard error.
* Indicates statistical significance.

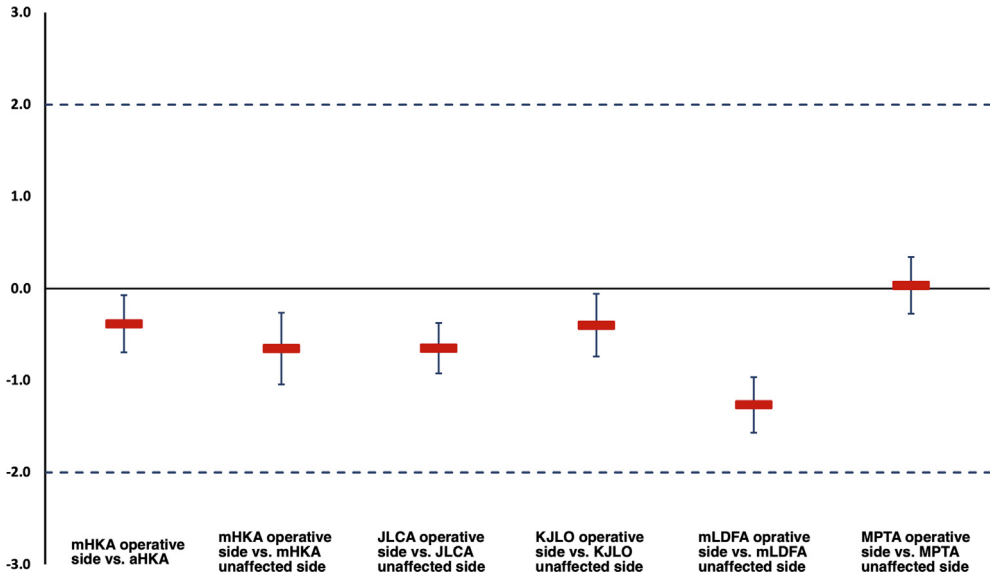


**Figure 3.** Equivalence between postoperative alignment of the operative knee following medial unicompartmental knee arthroplasty, and estimated pre-arthritic alignment parameters including the arithmetic hip-knee-ankle angle (aHKA, i.e., pre-arthritic mechanical axis) and the mechanical hip-knee-ankle angle (mHKA, i.e., mechanical axis), joint line congruence angle (JLCA) knee joint line obliquity angle (KJLO), mechanical lateral distal femoral angle (mLDFA), and medial proximal tibial angle (MPTA) of the contralateral unaffected knee. The dotted horizontal lines indicate the preset equivalence margins of +2.0° and −2.0°. The error bars indicate the 90% confidence interval.

**Table 3**
Distribution of knees by alignment category.

| | **Operative knee** | | **Estimated pre-arthritic alignment** | |
|---|---|---|---|---|
| | Preoperatively | Postoperatively | aHKA algorithm | Contralateral unaffected knee |
| Varus (mHKA ≥ 3.0°) | 96 (94%) | 40 (39%) | 44 (43%) | 52 (51%) |
| Neutral (mHKA 0° ± 3.0°) | 6 (6%) | 62 (61%) | 58 (57%) | 50 (49%) |
| Valgus (mHKA ≤ −3.0°) | 0 | 0 | – | – |

The distribution of knees per alignment category is presented in numbers and frequencies for the operative knee and both methods for estimated pre-arthritic alignment. *aHKA*, arithmetic hip-knee-ankle algorithm; *mHKA*, mechanical hip-knee-ankle angle.

### 3.3. Joint line congruence and obliquity and the contralateral unaffected knee

A total of 94 knees (92%) were restored within 3.0° of the JLCA of the contralateral unaffected knee, 79 knees (77%) within 2.0°, and 49 knees (48%) within 1.0°. With regard to KJLO, these figures were 87 knees (85%), 71 knees (70%), and 38 knees (37%), respectively. Mean postoperative JLCA was equivalent between the operative and contralateral unaffected knees with a mean difference of −0.65° (90% CI −0.92 to 0.37; $p < .001$) (Table 2; Figure 3). Similarly, mean postoperative KJLO of the operative knees and contralateral unaffected knees was equivalent, with a mean difference of −0.40° (90% CI −0.74 to −0.06; $p < .001$).

### 3.4. Femoral and tibial alignment and the contralateral unaffected knee

Postoperatively, both mean mLFDA and mean MPTA were equivalent between the operative and contralateral unaffected knees (Table 2, Figure 3).

### 3.5. Position of the weight-bearing axis and the contralateral unaffected knee

Postoperatively, the WBA of the operative knees passed through tibial zone 2 or C in 99 knees (97%) (Figure 4) and within ±1 tibial zone of the unaffected knees in all but one patient (99%).

The distribution of differences between postoperative alignment and estimated pre-arthritic alignment parameters is provided in the Appendix (Figure 1).

## 4. Discussion

This study found equivalence between postoperative coronal alignment parameters and estimated pre-arthritic alignment following robotic-assisted medial UKA, with 91% of knees restored within 3.0° of their pre-arthritic mechanical axis. Although absolute pre-arthritic alignment could not be determined, this study sought to verify restoration of pre-arthritic alignment through two distinct methods, including the aHKA algorithm and alignment parameters of the contralateral unaffected knee. Confirmed by both methods, our data demonstrated that in addition to resurfacing of the medial compartment, the knee is restored to its pre-arthritic coronal alignment by re-tensioning of the MCL, reconstructing both the mechanical axis and joint line congruence in patients that undergo robotic-assisted UKA for medial compartment OA.

Following conventional concepts in TKA, mechanical alignment (i.e., neutral alignment) has traditionally been considered the standard in UKA to improve outcomes and implant survivorship, regardless of the native alignment [9,28]. However, recent increased awareness of the widespread variability in anatomy of the individual knee [29] has challenged this "one-size-fits-all" concept. A study by Bellemans et al. [9] demonstrated that constitutional varus alignment of ≥3° was present in a substantial fraction of a young, non-OA population (25% out of 500 knees). Moreover, Hirschmann et al. [10] reported that the knee phenotypes representative of mechanical alignment targets in TKA (i.e., neutral mechanical axis with femoral and tibial joint lines perpendicular to the mechanical axis) were observed in only 5% out of 160 individuals with non-OA knees. In line with these observations, the present study found a large variability in pre-arthritic alignment, with an incidence of constitutional varus (≥3°) of 43% and 51% according to the aHKA algorithm and contralateral unaffected

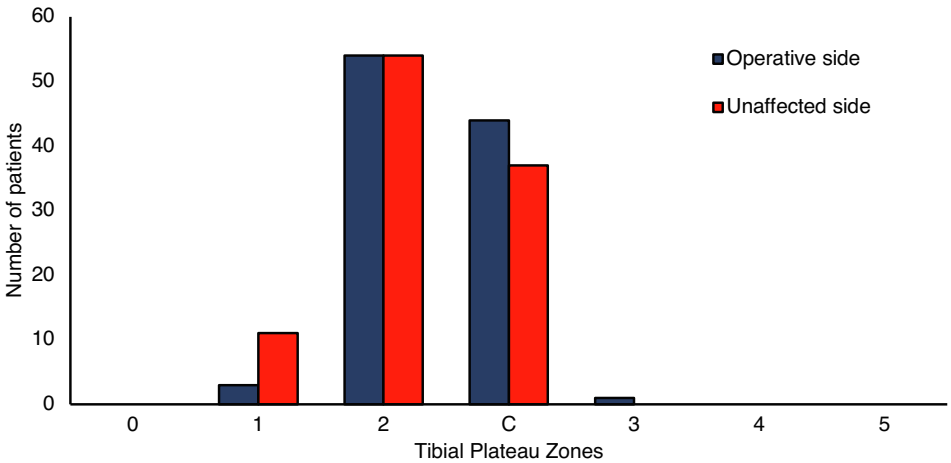


**Figure 4.** Distribution of knees according to the postoperative position of the weight-bearing axis (WBA) at the tibial joint line following medial unicompartmental knee arthroplasty. The postoperative position of the WBA was based on Kennedy and White's tibial zones [26].

knees, respectively (Table 3). These findings suggest that a systematic alignment approach in medial UKA may lead to non-physiological alignment and potentially compromised kinematics in a large proportion of knees with medial compartment OA.

In contrast to mechanical alignment, restoring the individual soft tissue balance may generate more natural knee kinematics, improved bone loading, and reduced residual stiffness and pain [30,31]. However, some have expressed concerns about undercorrecting the mechanical axis, as this may increase medial compartment loading and stress on the prosthesis [3,32,33]. Nevertheless, while the clinical advantage of a pre-arthritic alignment strategy over a systematic approach has yet to be demonstrated on a larger scale, evidence is emerging to supports its clinical justification. Plancher et al. [14] reported improved patient-reported outcomes at 10-year follow-up and longer implant survivorship among knees that were restored within ±3.0° of their pre-arthritic alignment, compared to knees restored to >3.0° outside of their pre-arthritic alignment after fixed-bearing medial UKA [14]. Moreover, a study by Kennedy et al. [6], including 891 knees, found that mobile-bearing medial UKA achieved successful functional outcomes and 12-year survivorship (93.2–93.6%) by restoring ligament tension and subsequent pre-arthritic alignment, independent of postoperative alignment of marked varus (10°), mild varus (5°), or neutral alignment. Hence, the authors [6] concluded that outcomes did not deteriorate with increased postoperative varus alignment.

The above observations by Plancher et al. [14] and Kennedy et al. [6] contribute to the notion that restoration of pre-arthritic alignment can yield successful long-term functional outcomes and survivorship, despite being "undercorrected" in varus alignment [6,14]. It could be suggested that the biomechanical advantages associated with recreating pre-arthritic alignment [30], added to improved designs and materials of contemporary UKA systems [34], may allow for larger postoperative varus alignment without clinical deterioration (e.g., implant wear or loosening). To reduce the risk of lateral compartment degeneration, however, restoration of pre-arthritic alignment in the present study was bounded by neutral alignment [3,20]. This technique therefore resembles a form of restricted kinematic alignment. Nevertheless, the optimal postoperative alignment after medial UKA remains debated. Several studies have advocated for a postoperative alignment between 1–4° of varus [5,7,8,35] to optimize outcomes. Considering the variance in coronal alignment of the nonarthritic population [9], as well as in the present study, it is likely that the majority of knees will be restored to within the range of 1–4° of varus. However, it remains unclear to what extent deviation from these margins is acceptable when utilizing a pre-arthritic alignment strategy, thus necessitating further research to evaluate the influence of recreating pre-arthritic alignment on postoperative outcomes following medial UKA.

Previous studies have shown that conventional mobile-bearing medial UKA restored coronal alignment close to or, similar to that of the contralateral unaffected knee [11,13]. However, both these studies [11,13] used the contralateral unaffected limb as sole factor for estimation of pre-arthritic alignment which, given the potential of constitutional asymmetry between both limbs may not always be reliable [36]. Therefore, to account for native asymmetry between both limbs, we utilized the validated aHKA algorithm as primary method to verify restoration of the pre-arthritic mechanical axis. The aHKA is computed from the MPTA and mLDFA which, in the absence of significant bone loss, are not affected by OA-related joint space narrowing [24]. Therefore, the aHKA should closely resemble the pre-arthritic mechanical axis. Interestingly, means of aHKA and mHKA of the contralateral unaffected knees appeared to be similar (Table1), yet, the variability in proportions of knees restored within ±3.0° of each pre-arthritic alignment method (91% and 79%, respectively) may reflect that some degree of native asymmetry between both sides was indeed present.

This study has several limitations. The first is inherent to the retrospective design which may have introduced selection bias. Second, functional outcomes and survivorship were not assessed in this study. Although previous studies have demonstrated excellent mid-term functional outcomes and implant survivorship following robotic-assisted medial UKA [37,38], future research is needed to further evaluate the clinical impact of a pre-arthritic alignment strategy. Third, radiographic outcomes were based on coronal plane measurements of weight-bearing long-leg radiographs and were therefore limited to a static comparison of alignment in full extension in the coronal plane only, whereas UKA aims to restore the three-dimensional alignment and knee kinematics. It remains to be determined whether alignment is restored in all three planes and further research is necessary to confirm restoration of MCL tension throughout the ROM. Nevertheless, the results of the present study demonstrate that pre-arthritic coronal alignment can indeed be effectively restored by re-tensioning of the MCL in robotic-assisted medial UKA and therefore support the rationale of a pre-arthritic alignment strategy.

## 5. Conclusions

Following robotic-assisted medial UKA, postoperative coronal alignment and estimated pre-arthritic alignment parameters were equivalent, with 91% of knees restored within 3.0° of their pre-arthritic mechanical axis. The results demonstrate that the knee is restored to its pre-arthritic alignment, reconstructing both the mechanical axis and joint line congruence by re-tensioning of the MCL in patients that undergo robotic-assisted medial UKA for medial compartment OA.

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**Declarations:**

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## Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Dr. Andrew Pearle is a consultant for Smith & Nephew and Depuy Synthes. Dr. Hendrik Zuiderbaan is a consultant for Smith & Nephew. Joseph Nguyen is an Editorial Board member of the American Journal of Sports Medicine and the Journal of Women's Sports Medicine. The other authors declare to have no potential conflict of interest.

## Appendix A. Supplementary material

Supplementary data to this article can be found online at https://doi.org/10.1016/j.knee.2023.01.005.

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