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Large variance in a lateral osteoarthritic population prior to and following lateral unicompartmental arthroplasty: An analysis of knee phenotypes

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A B S T R A C T

Background: Disagreement exists on the optimal coronal alignment target for lateral unicompartmental knee arthroplasty (UKA). An improved understanding of the distribution of coronal alignment and joint line orientation in lateral osteoarthritis (OA) might prove beneficial. The aim of this study was to evaluate the pre- and postoperative Coronal Plane Alignment of the Knee (CPAK) distribution following lateral UKA and to evaluate the association between phenotypic variation and patient-reported outcome measures (PROMs).
Methods: A surgeon's registry was retrospectively reviewed between 2012 and 2022 to identify patients who received primary lateral UKA for advanced, lateral compartment OA. Radiographic measurements were performed, and CPAK phenotypes were determined. The Knee Injury and Osteoarthritis Outcome Score (KOOS), Kujala, and patient satisfaction were analyzed at one-year and two-year follow-up.
Results: A total of 305 knees were included. Preoperatively, seven phenotypes were observed and CPAK3 (54.1%) was most commonly observed. Postoperatively, all nine phenotypes were observed and CPAK6 (32.8%) was predominant. Preoperatively, 23.6% did not have a prearthritic valgus alignment. No significant differences in PROMs were found between individual phenotypes or between preserved and altered phenotypes.
Conclusion: Coronal alignment and joint line orientation were highly variable within a lateral compartment OA cohort. However, no association was demonstrated between superior postoperative PROMs and phenotype variation or phenotype preservation, which might suggest that there is not one universal optimal alignment target. Interestingly, 23.6% of knees with lateral compartment OA did not have a prearthritic valgus alignment, which may have been affected by joint line orientation.

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1. Introduction

Unicompartmental knee arthroplasty (UKA) is an effective surgical treatment for lateral compartment knee osteoarthritis (OA) when non-operative treatments have failed [1–4]. Traditionally, the surgical aim of lateral UKA is to resurface the lateral compartment and avoid overcorrection into varus in order to prevent medial compartment degeneration [5]. However, disagreement exists about the optimal coronal alignment target. An improved understanding of the distribution of coronal alignment and joint line orientation in knees with lateral compartment OA can aid in determining superior patient-individualized alignment.

Although the conventional coronal alignment nomenclature was solely focused on neutral, varus and valgus alignment, several studies have shown a variation in coronal alignment and broad phenotype distribution in healthy knees and knees with generalized OA [6–8]. MacDessi et al. [8] introduced the Coronal Plane Alignment of the Knee (CPAK) classification which differentiates knees into nine CPAK phenotypes, based on their coronal alignment and joint line obliquity. The study included symptomatic osteoarthritic patients, not differentiating between the various forms of OA such as isolated medial-, lateral- and patellofemoral OA [8].

Lateral compartment OA is an uncommon form of OA with a prevalence of approximately 10% and likely contributed minimally to Macdessi's outcomes [8,9]. Additionally, the biomechanical characteristics of the lateral compartment of the knee differ considerably to the medial compartment [1,10]. Hence, it is interesting to evaluate the phenotypic distribution specifically for lateral compartment OA. Furthermore, the association between phenotype variability and patient-reported outcome measures (PROMs) remains unknown.

The study aimed to evaluate the pre- and postoperative CPAK distribution for patients who underwent primary lateral UKA for lateral compartment OA and to compare PROMs between CPAK phenotypes.

2. Materials and methods

2.1. Study design

Following IRB approval (#2021-0627), the registry of the senior author (ADP) was reviewed for patients who received a primary, fixed-bearing, cemented lateral UKA using a robotic-arm assisted system (Restoris MCK System; MAKO System, Stryker, Fort Lauderdale, Florida, USA) for lateral compartment OA between March 2012 and March 2022. Cases were included if they had pre- and postoperative anteroposterior (AP) long-leg weightbearing radiographs. Cases with a history of prior lower limb arthroplasty or femoral- or tibial fractures on either side were excluded. Additionally, available postoperative PROMs were collected for all included patients at one-year and two-year follow-up.

Lateral UKA was indicated in cases of symptomatic lateral compartment OA (Kellgren-Lawrence [KL] [11] grade $\geq$3). Radiographic patellofemoral OA without clinical symptoms was not a contraindication [12]. Medial compartment OA (KL $\geq$3), clinical symptoms of anterior-cruciate ligament deficiency (knee instability), signs of inflammatory arthritis and clinical symptoms of patellofemoral pain syndrome were contraindications.

2.2. Surgical technique

All surgeries were performed by the senior author (ADP), who had extensive experience in both medial- and lateral UKA. A three-dimensional model, based on a preoperative computer tomography (CT) scan, and robotic navigation were used for preoperative virtual implant planning and real-time intraoperative alterations. The surgical goal was to resurface the lateral compartment and target the coronal alignment to neutral or minimal valgus to restore prearthritic alignment and avoid the progression of OA in the medial compartment. This is achieved by ministering to internally rotating the tibia, avoiding tibial overhang anteriorly and avoiding overtightening of the lateral flexion space. Furthermore, special care was taken into registering if the femur and tibia line up through the whole range of motion. The surgical technique has been explained in detail [13].

2.3. Radiographic evaluation

Radiographic imaging was performed preoperatively and at six weeks postoperatively, according to a standardized protocol. Measurements including the mechanical hip-knee-ankle angle (mHKA), mechanical lateral-distal-femoral-angle (mLDFA) and medial-proximal-tibial-angle (MPTA) were measured on long-leg weightbearing radiographs and independently performed by two observers (GB and LR) (Figure 1) [8]. Inter-rater reliability, assessed using the Interclass Correlation Coefficient (ICC) was good (ICC range 0.82–0.87).

2.4. CPAK classification

The CPAK classification was used to determine knee phenotypes. The classification system is based on two independent factors and combines the arithmetic hip-knee-ankle angle (aHKA) and joint line obliquity (JLO) (Figure 2). The aHKA is

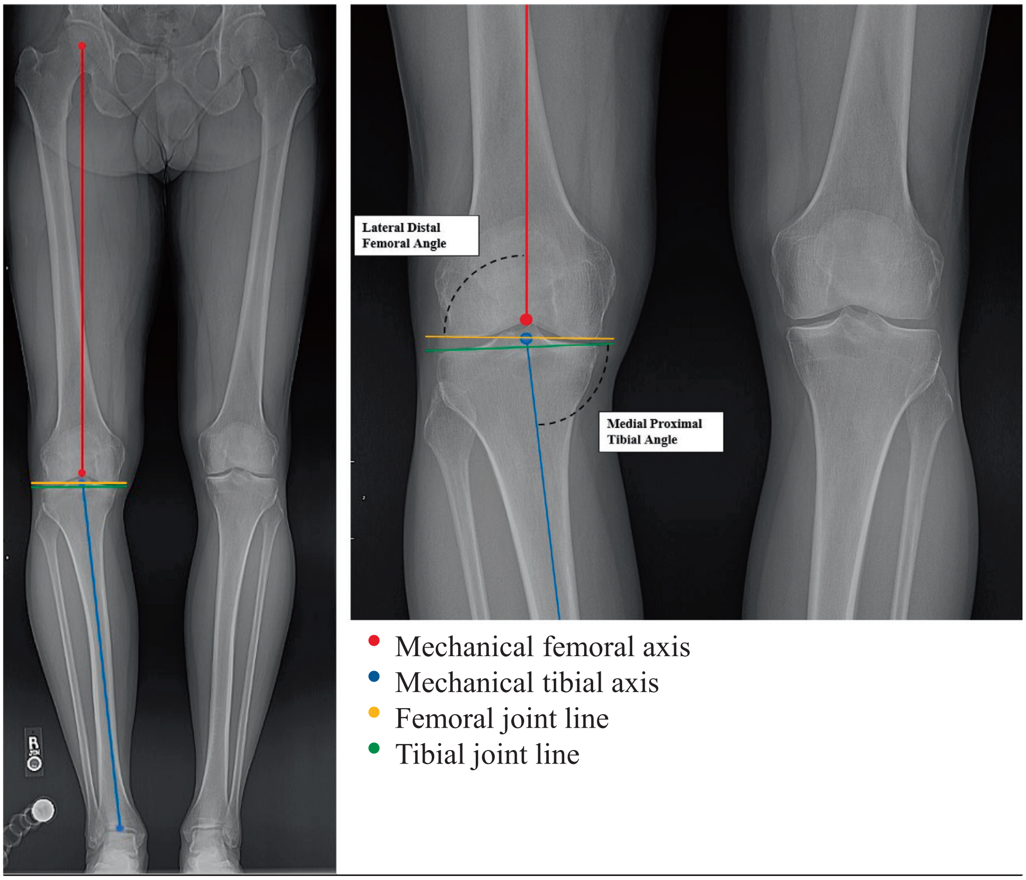

Figure 1. Measurement of MPTA and LDFA angles. Description of the measurement of the MPTA and LDFA angles which were required for determination of CPAK phenotypes. *CPAK; Coronal Plane Alignment of the Knee. MPTA; medial proximal tibial angle. LDFA: lateral distal femoral angle.*

calculated by subtracting the mLDFA from the MPTA and can be categorized in three subgroups: neutral (aHKA 0° ± 2°), varus (aHKA $\leq -2°$), and valgus (aHKA $\geq 2°$). JLO is determined by the sum of mLDFA and MPTA, and consists of three subgroups: apex neutral (JLO 180° ± 3°), apex distal (JLO $\leq 177°$), and apex proximal (JLO $\geq 183°$). The apex terminology describes the orientation of the joint line relative to a horizontal plane [8]. mLDFA and MPTA were measured on AP long-leg weightbearing radiographs.

2.5. Postoperative patient-reported outcome measures

The validated KOOS, JR [14] and Kujala [15] scores were collected at one-year and two-year follow-up. The PROMs were routinely collected through a digital, standardized questionnaire. Additionally, patient satisfaction was addressed using two anchor questions; 'What is the level of satisfaction with the overall function of the operative knee?' (very satisfied, satisfied, neutral, dissatisfied, very dissatisfied) and 'would you have undergone the surgery knowing that the current state of your knee would be the outcome of the surgery?' (yes, no). To determine satisfactory PROMs, patient acceptable symptom state (PASS) thresholds were defined using an anchor-based method [16]. As dichotomous outcomes were necessary to determine PASS thresholds and satisfaction was determined on the 5-point patient satisfaction Likert scale, patients who were 'very satisfied' and 'satisfied' were defined as 'satisfied'. To discriminate between satisfied- and non-satisfied patients, Receiver Operating Characteristic (ROC) curve analyses were performed. Optimal threshold for each score was determined at the point where sensitivity and specificity were maximal (Youden Index) [17].

2.6. Statistical analysis

Analyses were performed using SPSS version 29.0 software (SPSS, Inc., Chicago, IL, USA). Continuous variables were presented as means with standard deviations (SD) and discrete variables as frequencies with percentages (%). Data was tested for a normal distribution using the Shapiro-Wilks test and compared using independent two-sample t-tests, one-way ANOVA, or Kruskal-Wallis test depending on the number of independent variables and distribution. Categorical data was

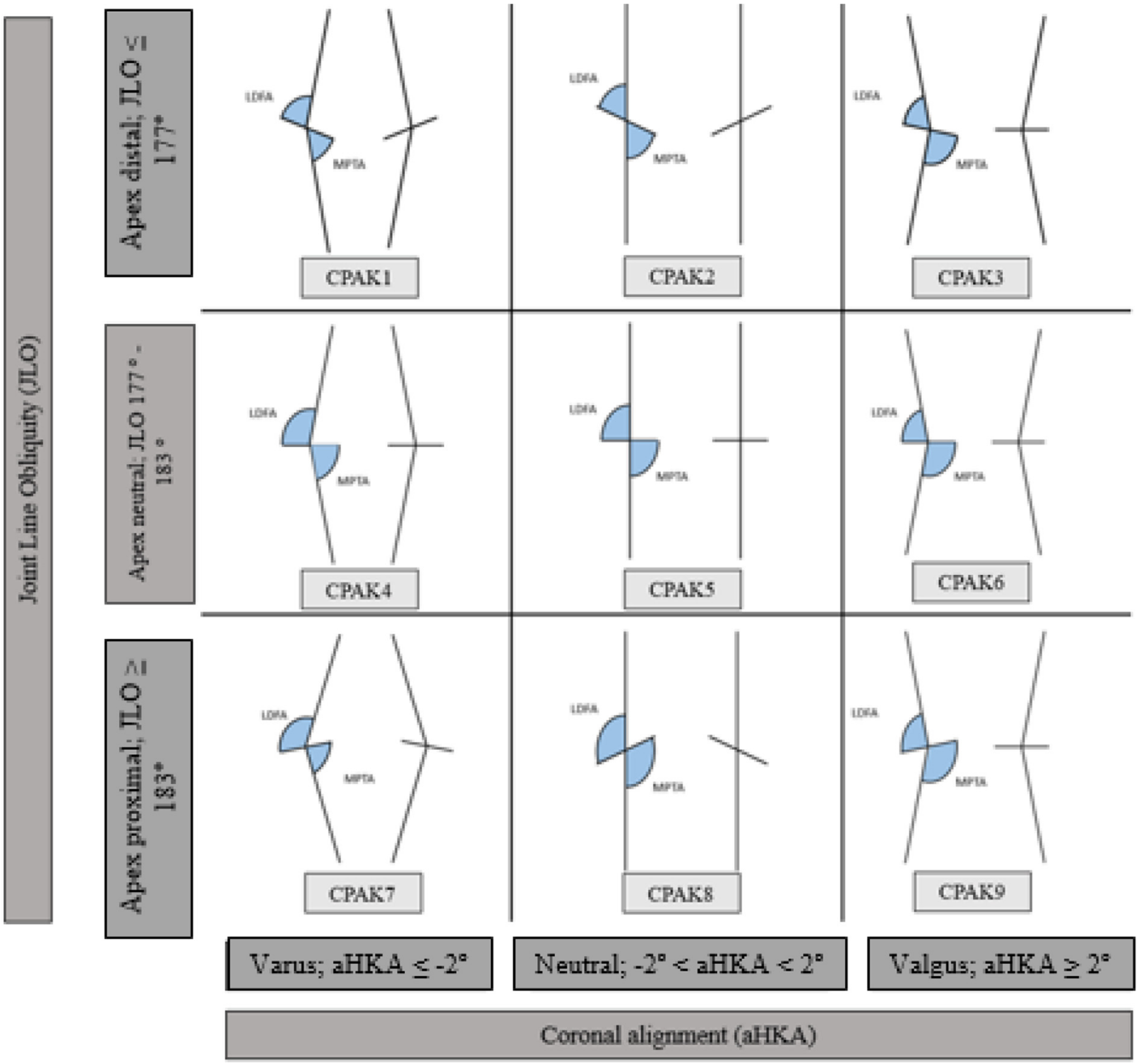

Figure 2. Coronal Plane Alignment of the Knee (CPAK). Description of the nine CPAK phenotypes. *CPAK; Coronal Plane Alignment of the Knee. JLO; joint line obliquity. aHKA; arithmetic Hip-Knee-Ankle angle.*

compared using Chi-squared test or Fisher's exact test, and ordinal data was compared using the Wilcoxon's signed-rank test. Multivariable linear- and logistic regression analyses were performed to determine differences in PROMs between groups, while adjusting for the potential confounding effects of sex, age, body-mass index (BMI) and follow-up. Statistical level of significance was set to p <0.05.

3. Results

3.1. Patient demographics and baseline radiographic characteristics

A total of 305 knees were included for evaluation of pre- and postoperative CPAK phenotyping. Mean age was 64.0 ± 11.0 years, mean BMI was 26.6 ± 4.6, and 58.0% of patients were female (Table 1).

3.2. Preoperative radiographic evaluation

Seven phenotypes were observed preoperatively. CPAK3 was the most common observed phenotype (54.1%), followed by CPAK6 (21.0%) and CPAK2 (16.1%). Valgus aligned CPAK phenotypes were predominant (76.4%) and most joint lines were apex distally positioned (71.8%) (Figure 3; Figure 4).

Table 1
Demographics and radiographic measurements of 305 knees.

Demographics		Mean ± SD, or N (%)
Age (years)		64.0 ± 11.0
Follow-up (years)		2.0 ± 0.0
BMI (kg/m^2)		26.6 ± 4.6
Laterality of UKA	Right	170 (55.7%)
	Left	117 (38.4%)
	Bilateral	18 (5.9%)
Sex	Female	177 (58.0%)
KL medial compartment	3	28 (9.2%)
	4	277 (90.8%)
Radiographic measurements		
		Mean ± SD
Preoperative mHKA		174.0° ± 3.8°
Postoperative mHKA		176.8° ± 2.2°
Preoperative aHKA		183.7° ± 2.7°
Postoperative aHKA		182.4° ± 2.1°
Preoperative JLO		175.1° ± 3.3°
Postoperative JLO		177.9° ± 3.3°

Demographics and radiographic measurements were presented as mean ± standard deviation (SD), or in numbers with the frequency in parentheses for the total cohort of 305 patients. Postoperative radiographic measurements were determined after six weeks. *UKA; unicompartmental knee arthroplasty. BMI; body-mass index. KL; Kellgren-Lawrence grade. mHKA; mechanical hip-knee-ankle angle. aHKA; arithmetic hip-knee-ankle angle. JLO; joint line obliquity.*

CPAK2, characterized by a neutral prearthritic coronal alignment and apex distally oriented joint line, was significantly more prevalent in male patients (male: 59.1%; female: 40.9%, p = .008). Additionally, CPAK2 was significantly more prevalent in patients aged between 50 and 70 years than in the other age groups (50–70: 55.1%; <50: 20.4%; >70: 24.5%, p = .022). Similarly, CPAK6, characterized by a valgus prearthirtic coronal alignment and neutrally oriented joint line, was significantly more common in patients 50–70 years old (50–70: 64.1%; <50: 1.6%; >70: 34.4%, p = .048) (Table 2).

3.3. Postoperative radiographic evaluation

All nine phenotypes were observed postoperatively. CPAK6 was the most common phenotype (32.8%), followed by CPAK3 (22.0%) and CPAK5 (21.3%). Valgus aligned phenotypes (59.4%), and neutrally oriented joint lines (55.1%) were most common (Figure 3).

CPAK2 was significantly more prevalent in male patients (male: 67.4%; female: 32.6%, p <.001), whereas CPAK6 was significantly more prevalent in female patients (male: 27.0%; female: 73.0%, p <.001). CPAK2 remained the most common phenotype following surgery in the age group between 50 and 70 years old (50–70: 76.7%; <50: 9.3%; >70: 14.0%, p = .041) (Table 2).

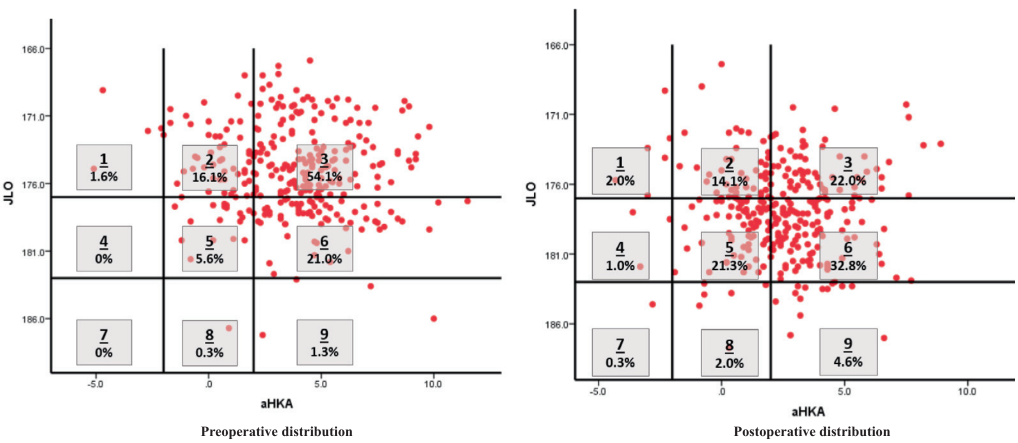

Figure 3. Preoperative and postoperative CPAK distribution. The preoperative and postoperative CPAK distribution was presented as the proportion of each individual CPAK phenotype as fraction of the total cohort of 305 knees. *CPAK; Coronal Plane Alignment of the Knee. JLO; joint line obliquity. aHKA; arithmetic Hip-Knee-Ankle angle.*

Table 2
Preoperative and postoperative CPAK distribution by sex, obesity and age groups.

CPAK	N (%)		P-value¶	N (%)		P-value¶	N (%)			P-value×
	Male	*Female*		*Obese*	*Not obese*		*<50 years*	*50–70 years*	*>70 years*	
Preoperative										
1	5 (100.0%)	–	0.122	–	5 (100.0%)	1.000	–	3 (60.0%)	2 (40.0%)	0.724
2	29 (59.1%)	20 (40.9%)	0.008*	6 (15.8%)	32 (84.2%)	0.311	10 (20.4%)	27 (55.1%)	12 (24.5%)	0.022*
3	61 (37.0%)	104 (63.0%)	0.551	27 (22.3%)	94 (77.7%)	0.912	16 (9.7%)	100 (60.6%)	49 (29.7%)	0.992
4	–	–	–	–	–	–	–	–	–	–
5	5 (29.4%)	12 (70.6%)	0.294	2 (15.4%)	11 (84.6%)	0.554	1 (5.9%)	11 (64.7%)	5 (29.5%)	0.861
6	26 (40.6%)	38 (59.4%)	0.813	14 (30.4%)	32 (69.6%)	0.123	1 (1.6%)	41 (64.1%)	22 (34.5%)	0.048*
7	–	–	–	–	–	–	–	–	–	–
8	–	1 (100.0%)	1.000	1 (100.0%)	–	1.000	1 (100.0%)	–	–	1.000
9	2 (50.0%)	2 (50.0%)	1.000	–	2 (100.0%)	1.000	–	3 (75.0%)	1 (25.0%)	0.853
Postoperative										
1	5 (83.3%)	1 (16.7%)	0.094	–	5 (100.0%)	1.000	–	4 (66.7%)	2 (33.3%)	0.732
2	29 (67.4%)	14 (32.6%)	<0.001*	10 (30.3%)	23 (69.7%)	0.223	4 (9.3%)	33 (76.7%)	6 (14.0%)	0.041*
3	25 (37.3%)	42 (62.7%)	0.382	11 (22.0%)	39 (78.0%)	0.992	7 (10.4%)	38 (56.7%)	22 (32.8%)	0.763
4	3 (100.0%)	–	1.000	–	3 (100.0%)	1.000	1 (33.3%)	2 (66.7%)	–	0.261
5	34 (52.3%)	31 (47.7%)	0.064	9 (19.1%)	38 (80.9%)	0.592	9 (13.8%)	34 (52.3%)	22 (33.8%)	0.222
6	27 (27.0%)	73 (73.0%)	<0.001*	18 (24.3%)	56 (75.7%)	0.561	8 (8.0%)	57 (57.0%)	35 (35.0%)	0.364
7	–	1 (100.0%)	1.000	–	1 (100.0%)	1.000	–	1 (100.0%)	–	1.000
8	1 (16.7%)	5 (83.3%)	0.412	–	6 (100.0%)	1.000	–	5 (83.3%)	1 (16.7%)	0.482
9	3 (21.4%)	11 (78.6%)	0.111	2 (20.0%)	8 (80.0%)	0.874	–	11 (78.6%)	3 (21.4%)	0.282

Preoperative and postoperative CPAK distributions were presented in numbers with the frequencies in parentheses and separately presented by sex, obesity and age groups. *CPAK; Coronal Plane Alignment of the Knee. Obesity; body-mass index* $\geq$*30 kg/m*^{2}.
¶ Independent sample *t*-test.
× Kruskal-Wallis test.
* Signficant value.

3.4. Postoperative patient-reported outcome measures

PROMs were collected for 188 patients at one-year follow-up and for 145 knees at two-year follow-up. At two-years of follow-up, the mean KOOS, JR for the total cohort was 86.2 ± 13.7 and mean Kujala score was 84.8 ± 15.0. Of all patients, 93.1% were either ‘very satisfied’ or ‘satisfied’ and 93.8% of patients reported that they would have undergone the surgery again (Table 3).

When comparing PROMs between individual CPAK phenotypes, PROMs did not differ significantly (Table 3). Additionally, no significant association was observed between preservation of CPAK phenotypes and superior PROMs (Table 4). Initially, patients with preservation of CPAK5 had a significantly higher Kujala score than patients who had an altered CPAK5 phenotype postoperatively (preservation: 97.6 ± 2.6; alteration: 79.0 ± 15.6, $p = 0.015$) (Table 4). However, after adjusting for the potential confounders, this difference did not remain significant (β: −0.809 [−1.433 to −0.416], $p = 0.066$), as age had a significant effect (β: −0.385 [−0.985 to −0.118], $p = 0.027$). Additionally, postoperative PROMs did not significantly change from one-year to two-years postoperative (Figure 5).

4. Discussion

The main finding of this study was that prearthritic coronal alignment and joint line orientation of lateral compartment osteoarthritic knees demonstrated a large pre- and postoperative variability. Interestingly, 23.6% of knees with isolated lateral compartment OA did not have a prearthritic valgus alignment. No significant differences in postoperative PROMs were found between individual CPAK phenotypes or between preservation or alteration of CPAK phenotypes.

Recent studies have provided evidence to support a patient-specific, phenotype-dependent surgical approach of UKA [6–8]. These studies observed that approximately 15% of the healthy and generalized OA population have a neutral coronal alignment with a neutral joint line, suggesting that coronal alignment and joint line orientation is highly variable. Isolated lateral compartment OA is a relatively rare form of OA with a reported prevalence of 10% [9,18]. To the authors’ knowledge, no previous study analyzed the phenotype distribution specifically in a population with isolated lateral compartment OA prior to- and following lateral UKA. Moreover, no study has analyzed the association between phenotype distribution and postoperative PROMs in a lateral OA cohort.

This study demonstrated a highly variable preoperative CPAK phenotype distribution. This emphasizes the high level of coronal alignment- as well as joint line orientation diversity within a specific cohort of patients with isolated lateral compartment OA. This study was the first to demonstrate this reported diversity. The observed diversity might suggest that there is not one universal optimal alignment target and that a patient-, and knee phenotype specific approach might be superior.

Table 3
Postoperative PROMs of preoperative CPAK phenotypes.

	Phenotypes							
Variables	Total	CPAK1	CPAK2	CPAK3	CPAK5	CPAK6	CPAK9	*P*-value[¶]
One-year postoperative PROMs								
N of knees	188	5	34	88	11	47	3	
KOOS, JR								
Mean ± SD	83.0 ± 12.6	88.1 ± 13.3	79.2 ± 11.3	82.6 ± 13.9	82.3 ± 14.5	83.5 ± 11.0	100.0 ± 0.0	0.359
N (%) achieved PASS (≥70.0)	165 (87.7%)	4 (80%)	30 (88.2%)	76 (86.4%)	10 (90.9%)	42 (89.4%)	3 (100%)	0.811
N (%) achieved maximum (100)	56 (29.8%)	2 (40%)	6 (17.6%)	31 (35.2%)	4 (36.4%)	10 (21.3%)	3 (100%)	0.193
Kujala								
Mean ± SD	82.3 ± 12.3	84.2 ± 12.0	81.3 ± 14.8	84.7 ± 13.1	90.9 ± 8.4	80.4 ± 12.6	86.1 ± 9.3	0.852
N (%) achieved PASS (≥70.0)	140 (74.4%)	5 (100%)	21 (82.4%)	69 (89.8%)	10 (90.0%)	34 (89.4%)	3 100%)	0.714
N (%) achieved maximum (100)	66 (35.1%)	3 (60%)	15 (47.0%)	30 (34.1%)	2 (18.2%)	15 (31.9%)	0 (0%)	0.498
Patient satisfaction								
N (%) answered ‘very satisfied’ or ‘satisfied’	177 (94.1%)	4 (80%)	31 (91.2%)	85 (96.6%)	10 (90.9%)	44 (93.6%)	3 (100%)	0.928
Re-do surgery								
N (%) answered ‘yes’	174 (92.6%)	4 (80%)	31 (91.2%)	84 (95.4%)	8 (72.7%)	44 (93.6%)	3 (100%)	0.956
Two-year postoperative PROMs								
N of knees	145	2	23	75	8	35	2	
KOOS, JR								
Mean ± SD	86.2 ± 13.7	100.0 ± 0.0	83.4 ± 12.1	86.0 ± 14.9	86.8 ± 15.6	86.8 ± 12.0	100.0 ± 0.0	0.421
N (%) achieved PASS (≥70.0)	130 (89.7%)	2 (100%)	21 (91.3%)	65 (86.7%)	7 (87.5%)	33 (94.3%)	2 (100%)	0.835
N (%) achieved maximum (100)	56 (38.6%)	2 (100%)	6 (26.1%)	28 (37.3%)	4 (50.0%)	14 (40.0%)	2 (100%)	0.074
Kujala								
Mean ± SD	85.0 ± 15.0	89.0 ± 0.0	88.0 ± 17.0	92.0 ± 17.0	92.0 ± 11.0	85.0 ± 14.0	88.0 ± 4.0	0.563
N (%) achieved PASS (≥70.0)	123 (84.8%)	2 (100%)	21 (91.3%)	61 (81.3%)	7 (87.5%)	30 (85.7%)	2 (100%)	0.815
N (%) achieved maximum (100)	54 (37.2%)	1 (50.0%)	12 (52.2%)	21 (41.3%)	3 (37.5%)	17 (48.6%)	0 (0.0%)	0.674
Patient satisfaction								
N (%) answered ‘very satisfied’ or ‘satisfied’	135 (93.1%)	2 (100%)	22 (95.7%)	70 (93.3%)	7 (87.5%)	32 (91.4%)	2 (100%)	0.954
Re-do surgery								
N (%) answered ‘yes’	136 (93.8%)	2 (100%)	22 (95.7%)	68 (91.1%)	8 (100%)	34 (97.1%)	2 (100%)	0.832

One-year and two-year postoperative patient-reported outcome measures (PROMs) were presented for the total cohort of patients reporting on PROMs and for each postoperative CPAK phenotype individually. Continuous variables were presented as mean ± standard deviation (SD) and dichotomous variables in numbers with frequencies (%). *CPAK; Coronal Plane Alignment of the Knee. aHKA; arithmetic hip-knee-ankle angle. KOOS JR; Knee Injury and Osteoarthritis Outcome Score for Joint Replacement.*
*Significant value.
¶ Kruskal-Wallis test.

Table 4
Two-year postoperative PROMs according to preservation of CPAK phenotype.

	N (%) of knees	KOOS JR.[×]	Kujala[×]	Patient satisfaction[¶]	Re-do Surgery[¶]
Preservation of CPAK phenotype, total cohort					
Preservation	61 (42.1%)	86.4 ± 13.6	83.6 ± 15.0	91.9%	95.1%
Altered	84 (57.9%)	86.1 ± 13.9	85.5 ± 15.1	94.0%	94.0%
P-value		0.438	0.267	0.418	0.539
Preservation of CPAK1					
Preservation	1 (50.0%)	100.0 ± 0.0	–	100.0%	100.0%
Altered	1 (50.0%)	100.0 ± 0.0	89.0 ± 0.0	100.0%	100.0%
P-value					
Preservation of CPAK2					
Preservation	9 (29.1%)	84.1 ± 10.3	82.8 ± 16.4	100.0%	100.0%
Altered	14 (70.9%)	82.7 ± 14.0	91.1 ± 8.1	91.7%	91.7%
P-value		0.399	0.111	0.522	0.522
Preservation of CPAK3					
Preservation	22 (29.3%)	85.2 ± 16.3	80.0 ± 17.1	91.3%	91.3%
Altered	53 (70.7%)	86.3 ± 14.4	83.5 ± 16.6	94.2%	92.2%
P-value		0.384	0.237	0.639	0.901
Preservation of CPAK5					
Preservation	5 (62.5%)	93.7 ± 10.3	97.6 ± 2.6	100.0%	100.0%
Altered	3 (37.5%)	69.6 ± 14.5	79.0 ± 15.6	66.7%	100.0%
P-value		0.107	0.015*	0.375	
Preservation of CPAK6					
Preservation	18 (51.4%)	84.9 ± 12.5	82.7 ± 13.6	84.2%	94.7%
Altered	17 (48.6%)	88.9 ± 11.4	89.1 ± 14.3	100.0%	100.0%
P-value		0.175	0.142	0.234	0.543
Preservation of CPAK9					
Preservation	2 (100%)	100.0 ± 0.0	88.0 ± 4.0	100.0%	100.0%
Altered	–	–	–	–	–
P-value					

Two-year postoperative patient-reported outcome measures (PROMs) were presented for preserved and altered CPAK phenotype, described as mean ± standard deviation (SD) or in frequencies (%). Percentages presented the proportion of patients who were either 'very satisfied' or 'satisfied' or would undergo the surgery again. *CPAK; Coronal Plane Alignment of the Knee. aHKA; arithmetic hip-knee-ankle angle. KOOS JR; Knee Injury and Osteoarthritis Outcome Score for Joint Replacement.*

[×] Independent sample *t*-test.

[¶] According to the Chi-square test or Fisher's exact test.

[*] Significant value.

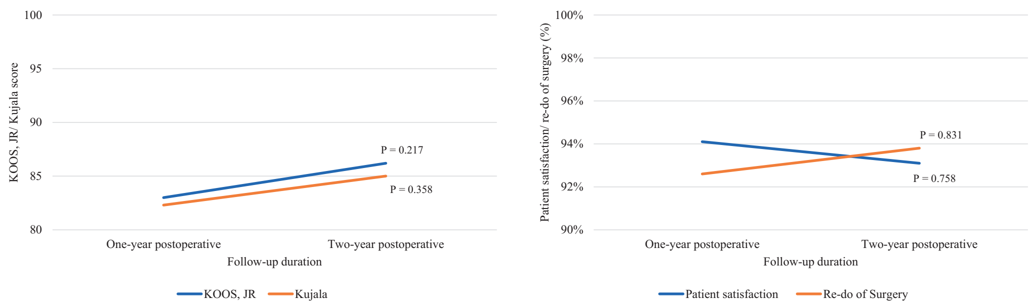

Figure 4. Change in PROMs from one-year to two-years postoperatively. Change from one-year to two-years postoperative PROMs. 188 patients reported on one-year PROMs and 145 patients reported on two-year PROMs. Percentages for patient satisfaction presented the proportion of patients who were either 'very satisfied' or 'satisfied' and percentages for redo of surgery presented the proportion of patients who would undergo the surgery again if they could choose again. *P*-value dictated the statistical significance of change from one-year to two-years postoperatively. *KOOS JR; Knee Injury and Osteoarthritis Outcome Score for Joint Replacement. Significance tested with the one-sample t-test. *Significant value.*

Additionally, it was observed that 76.4% of the preoperative cohort had a valgus alignment (CPAK3, -6 and -9). The high prevalence of valgus aligned phenotypes observed in the present study is in line with existing literature [19]. Valgus aligned knees have increased load on the lateral compartment, based on the morphology of the joint surfaces and the mechanical axis of the lower limb. Due to increased load, the lateral compartment is more prone to the progression of OA [9,10,20]. However, since lateral compartment OA is believed to be a valgus-related disease, it is intriguing to note that 23.6% of patients within this lateral compartment OA cohort did not demonstrate a prearthritic valgus aligned knee. Patients with

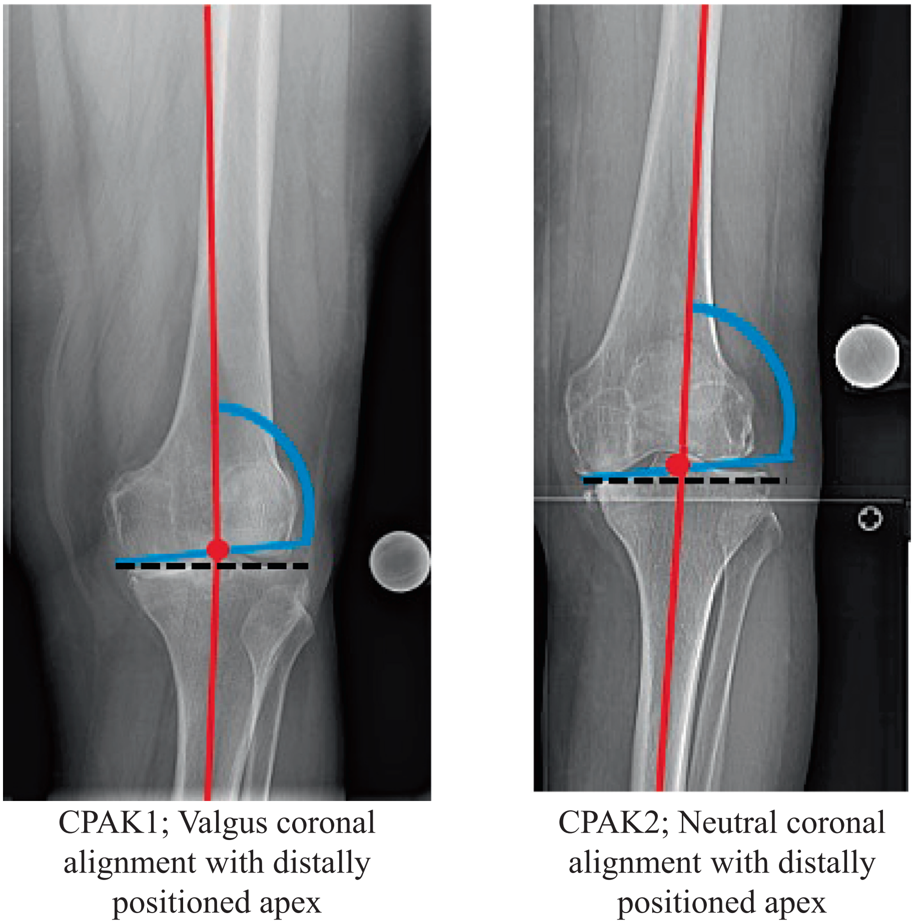

Figure 5. Possible correlation between a higher situated lateral compartment and a higher peak load. The higher situated lateral compartment might have resulted in a higher peak load in the lateral compartment, causing increased progression of osteoarthritis.

a prearthritic neutral alignment comprised 22.0% (CPAK2, -5 and -8) and patients with a prearthritic varus alignment comprised 1.6% (CPAK1, -4 and -7). Interestingly, within both sub-cohorts, the CPAK phenotypes with the apex distally positioned (CPAK1 and -2) were predominant (varus subgroup; CPAK1: 1.6%, CPAK4: 0%, CPAK7: 0%) (neutral subgroup; CPAK2; 16.1%, CPAK5: 5.6%, CPAK8: 0.3%). In the coronal plane, a distally positioned apex is characterized by the lateral compartment situated higher than the medial compartment, potentially resulting in a higher peak load in the lateral compartment (Figure 5). This might result in increased progression of OA in the lateral compartment. Future biomechanical research should evaluate this hypothesis.

MacDessi [8] and Hirschmann [6] investigated phenotype distribution in non-arthritic and generalized OA cohorts. Macdessi et al. observed that neutral alignment with apex distally positioned joint line (CPAK4) was predominant [8]. The discrepancy with our outcomes can be explained by the previously mentioned morphology of progressive lateral compartment OA since we solely evaluated patients with isolated lateral compartment OA. Furthermore, the prevalence of knees with an apex distally positioned joint line in a generalized OA cohort reported by Macdessi et al. [8] (67.0%) is similar to the prevalence of apex distally positioned knees reported in this lateral compartment OA cohort (71.8%), which might suggest that progression of OA does not affect the morphology of the joint line.

Postoperatively, variability of the phenotype distribution increased. Initially, it was hypothesized that postoperative variability would decrease as all patients were treated with the same surgical approach with the same surgical goal of coronal realignment to 0° to 4° of valgus. The increase in phenotype variability might be caused by an unaccounted-for factor. Mochizuki et al. [21] reported that, in addition to component positions, several intrinsic factors including preoperative rotational alignment, knee range of motion and tibial torsion affected postoperative rotational lower limb alignment, which might have influenced the increase in variability of distribution in this study.

Short-term postoperative PROMs observed in the present study were satisfactory. Our data suggested that the association between the CPAK phenotypic classification and patient outcomes is minimal. Initially, this study noted that patients with preservation of CPAK5 had a significantly higher Kujala score than patients who had an altered CPAK5 phenotype postoperatively. However, after adjusting for potential confounders, this difference did not remain significant, as age had a significant confounding effect. Neither Howell et al. [22] nor Kaneko et al. [23], who analyzed the Hirschmann phenotype distribution of medial, lateral and generalized OA, concluded a significant difference in PROMs between phenotypes [6]. However, this is the first study evaluating the association between knee phenotypes of a lateral compartment OA cohort and PROMs, and additional studies are necessary to determine a final conclusion of this association.

This study has several limitations, including the retrospective study design which might have caused selection bias. Second, some phenotypes were absent. This scarcity made inter-phenotype analyses of PROMs underpowered and thus were unable to be conducted. Nonetheless, this study represented the largest cohort to date with 305 patients that described the distribution of CPAK phenotypes in knees with lateral compartment OA. Third, the JLO angle describes the combined femoral and tibial joint line as a single value, and the femoral- and tibial joint line orientations can differ considerably [6]. As CPAK utilizes the JLO, this difference is not accounted for in the present study. Furthermore, CPAK does not take the sagittal alignment into account. Some literature has suggested that modification of the tibial posterior slope is essential in achieving native knee kinematics [24,25]. Knee phenotyping remains a relatively novel issue in knee arthroplasty and will require additions regarding the previously mentioned shortcomings of CPAK. However, up until now, CPAK phenotyping has already shown some clinical relevance in phenotype-specific alignment strategies [26,27].

5. Conclusion

Coronal alignment and joint line orientation were highly variable within a lateral compartment OA cohort. However, no association was demonstrated between superior postoperative PROMs and phenotype variation or phenotype preservation, which might suggest that there is not one universal optimal alignment target. Interestingly, 23.6% of knees with lateral compartment OA did not have a prearthritic valgus alignment which may have been affected by joint line orientation.

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CRediT authorship contribution statement

Roderick J.M. Vossen: Writing – original draft, Project administration, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Gaby V. ten Noever de Brauw:** Writing – review & editing, Visualization, Data curation. **Lindsey V. Ruderman:** Writing – review & editing, Methodology, Data curation. **Tarik Bayoumi:** Validation, Supervision, Methodology, Data curation, Conceptualization. **G.M.M.J. Kerkhoffs:** Writing – review & editing, Supervision, Conceptualization. **Hendrik A. Zuiderbaan:** Writing – review & editing, Supervision, Methodology, Conceptualization. **Andrew D. Pearle:** Supervision, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: 'Roderick J.M. Vossen, Gaby V. ten Noever de Brauw, Lindsey V. Ruderman, Tarik Bayoumi, G.M.M.J. Kerkhoffs declare that no conflict of interest; Hendrik A. Zuiderbaan declares that paid consultant for Smith&Nephew; Andrew D. Pearle declares that paid consultant for Smith&Nephew and DePuy Synthes'.

Appendix A. Supplementary material

Supplementary material to this article can be found online at https://doi.org/10.1016/j.knee.2024.05.010.

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