

ORIGINAL ARTICLE

Restoration of Preoperative Coronal Plane Alignment of the Knee Phenotypes and Clinical Outcomes Following Mechanically Aligned Total Knee Arthroplasty

Pichayut Wattanapreechanon MD¹,  Natthapong Hongku MD¹,  Ittiwat Onklin MD¹ 

¹ Department of Orthopaedics, Faculty of Medicine Vajira Hospital, Navamindradhiraj University, Bangkok 10300, Thailand

Corresponding author

Ittiwat Onklin

ittiwat@nmu.ac.th

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ABSTRACT

Objectives: This study aimed to determine the proportion of patients who exhibited a change in their coronal plane alignment of the knee (CPAK) classification after mechanically aligned (MA) total knee arthroplasty (TKA) and compare postoperative clinical outcomes between patients who restored their preoperative CPAK classification and those who did not.

Materials and Methods: This was a retrospective cohort study including 194 knees from 143 patients who underwent MA TKA between December 2021 and June 2024. Radiographic parameters, including pre- and postoperative lateral distal femoral angle and medial proximal tibial angle, were measured using long-leg standing radiographs to determine the CPAK classification. Postoperative Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) scores, range of motion (ROM), and surgical complications were recorded.

Results: The most common preoperative CPAK classification was type I (40.7%), followed by type II (22.7%) and type IV (14.9%). Furthermore, 36 (18.6%) knees were restored to their preoperative CPAK classification. No significant differences in postoperative ROM (flexion: 115° vs. 110°, $p = 0.445$; extension: 5° vs. 5°, $p = 0.770$) and WOMAC scores (13.56 ± 9.58 vs. 18.12 ± 10.64 , $p = 0.251$) were observed between the restored and non-restored groups. The surgical complication rates were 2.7% and 5.7% in the restored and non-restored groups, respectively.

Conclusion: A fixed MA TKA target may alter patients' CPAK classification post-operatively, with only a limited proportion achieving restoration of their preoperative CPAK classification. Restoration of the preoperative CPAK classification did not significantly influence clinical outcomes.

Keywords: coronal plane alignment, coronal plane alignment of the knee classification, mechanically aligned total knee arthroplasty, total knee arthroplasty

INTRODUCTION

Total knee arthroplasty (TKA) is the standard treatment for advanced knee osteoarthritis (OA). However, 10%–20% of patients reported dissatisfaction with surgical outcomes.¹ Several factors have been identified as contributing to persistent dissatisfaction after TKA, including younger age, poor preoperative psychological status, chronic opioid use, residual postoperative pain, limited postoperative range of motion (ROM), and changes in coronal knee alignment after surgery.^{2–6}

Historically, the restoration of coronal knee alignment to a neutral mechanical axis has been the primary goal in TKA.⁷ However, there is growing interest in the coronal plane alignment of the knee (CPAK) classification, and evidence suggests that postoperative changes from a patient's preoperative CPAK type may contribute to suboptimal outcomes.^{8,9}

The CPAK classification, introduced by Macdessi et al., categorizes knees into nine phenotypes based on constitutional limb alignment and joint line obliquity (JLO).¹⁰ Traditionally, surgeons perform mechanically aligned (MA) TKA using conventional instruments to cut the distal femur and proximal tibia perpendicular to their respective mechanical axes, aiming to achieve a neutral hip–knee–ankle (HKA) angle and a neutral JLO, consistent with CPAK type V. However, the most prevalent CPAK classification among Asian patients with knee OA is type I (varus HKA angle and apex-distal JLO; 49.3%–53.8%), followed by type II (neutral HKA angle and apex-distal JLO; 20.6%–25.4%) and type V (4%–5%).^{11,12} Targeting a neutral mechanical alignment may alter a patient's preoperative CPAK classification. However, this is not always achieved due to inaccuracies associated with conventional instruments, with up to 26%–30% of cases reported as outliers.^{13,14}

Despite the limited precision of conventional instruments in achieving a neutral mechanical axis, they may inadvertently restore a patient's preoperative CPAK classification. However, this phenomenon has been examined in only a limited number of studies. Corban et al. reported that, with conventional instrumentation in MA TKA, only 13% of patients coincidentally matched their preoperative CPAK type.¹⁵ Notably, these findings were derived from a non-Asian population, which may differ in the native CPAK distribution from Asian populations.

This study aimed to investigate the proportion of patients who exhibited a change in their CPAK classification after MA TKA. Additionally, this study

aimed to describe the distribution of CPAK classification among patients with knee OA undergoing TKA and compare postoperative clinical outcomes between patients who restored their original CPAK classification and those who did not.

MATERIALS AND METHODS

This retrospective study was approved by the Institutional Review Board of our institution (COA 174/68). This study included consecutive patients who underwent primary MA TKA performed by a fellowship-trained arthroplasty surgeon (PW) between December 2021 and June 2024. Patient data were obtained from the institution's electronic medical records and radiographic databases. The data were retrospectively retrieved using a standardized collection form and were collected by the primary author (PW). Patients who received a constrained TKA prosthesis, those who had severe preoperative bone loss, those who underwent computer navigation- or robotic-assisted surgery, and those who had incomplete radiographic data were excluded from the study.

A midvastus arthrotomy was performed. Then, the anterior cruciate ligament and osteophytes were excised. The proximal tibia was resected perpendicular to its anatomical axis using an extramedullary guide, whereas the distal femur was resected using an intramedullary guide set at a valgus angle of 5°. The extension gap was assessed using a spacer block. Medial soft-tissue release was performed as needed to achieve a symmetrical extension gap, whereas lateral release was performed for valgus knees. The femoral component size was determined using the anterior referencing technique, whereas the flexion gap and femoral rotation were assessed based on soft-tissue tension. Anterior, posterior, and chamfer cuts of the femur were performed. Trial components were inserted, and tibial tray rotation was determined using the self-aligned technique. Patellar tracking was evaluated using the no-thumb technique. All components were cemented, and an appropriately sized polyethylene insert was placed.

Preoperatively, all patients underwent standardized true anteroposterior (AP) and lateral knee radiographs, along with full-length standing radiographs, using a digital radiography system (Ysio Max, Siemens Healthineers, Germany). Postoperatively, true AP and lateral radiographs were obtained on the first postoperative day, and full-length standing radiographs were acquired at four weeks.

Radiographic parameters, including lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA), were measured using preoperative and postoperative full-length standing radiographs. The LDFA was measured as the lateral angle formed between the mechanical axis of the femur, and the distal femoral joint line. The femoral mechanical axis was defined as a line connecting the center of the femoral head to the most proximal point of the distal femoral intercondylar fossa, while the distal femoral joint line was defined as a line connecting the most distal points of the medial and lateral femoral condyles.

The MPTA was measured as the medial angle formed between the mechanical axis of the tibia and the proximal tibial joint line. The tibial mechanical axis was defined as a line connecting the center of the tibial intercondylar eminence to the center of the talus, whereas the proximal tibial joint line was defined as a line connecting the most proximal points of the medial and lateral tibial plateaus.

All measurements were performed twice by a single unblinded observer (PW), with a one-week interval, using the institution's digital picture archiving and communication system (EVInsight, PSP Co., Ltd., Thailand). The average values were used for analysis. The intraclass correlation coefficients for preoperative

LDFA, preoperative MPTA, postoperative LDFA, and postoperative MPTA were 0.928, 0.931, 0.849, and 0.916, respectively, indicating good to excellent intraobserver reliability.

The CPAK classification was determined based on the arithmetic HKA (aHKA) angle and JLO derived from LDFA and MPTA as previously described.¹⁰ The aHKA angle was calculated as $MPTA - LDFA$. aHKA angle $< -2^\circ$ was categorized as varus, between -2° and 2° as neutral, and $> 2^\circ$ as valgus. JLO was calculated as $MPTA + LDFA$. JLO $< 177^\circ$ was classified as apex-distal, between 177° and 183° as apex-neutral, and $> 183^\circ$ as apex-proximal. Patients were categorized into a CPAK classification based on their aHKA and JLO values (Figure 1). The Western Ontario and McMaster Universities Osteoarthritis Index (WOMAC) questionnaire score was obtained by an independent observer. ROM was measured using goniometer by the treating team, and surgical complications were recorded at the latest follow-up.

Normally distributed continuous data were presented as mean and standard deviation, and between-group comparisons were performed using the independent t-test. Non-normally distributed data were presented as median and interquartile range, and between-group comparisons were performed using

		Arithmetic HKA (aHKA=MPTA-LDFA)		
		VARUS	NEUTRAL	VALGUS
Joint line obliquity (JLO=MPTA+LDFA)	APEX DISTAL	Type I	Type II	Type III
	NEUTRAL	Type IV	Type V	Type VI
	APEX PROXIMAL	Type VII	Type VIII	Type IX

Figure 1 CPAK Classification Comprising Nine Phenotypes Based on JLO and aHKA

the Mann–Whitney U test. Categorical variables were presented as absolute numbers and percentages. Statistical analysis was performed using IBM SPSS Statistics for Windows version 31.0 (IBM Corp., Armonk, NY, USA). A p -value < 0.05 was considered statistically significant.

RESULTS

A total of 194 knees from 143 patients were included in this study (**Figure 2**). **Table 1** shows patients' demographic characteristics. The most common preoperative CPAK classification was type I (40.7%), followed by type II (22.7%) and type IV (14.9%), with the remainder distributed across type III and V–IX (**Figure 3**).

After MA TKA, the most common CPAK classification was type V (38.7%), followed by type IV (24.7%) and type VI (10.3%), with the remaining knees distributed across types I–III and VII–IX (**Figure 4**). Overall, 18.6% ($n = 36$) of the knees were restored to their preoperative CPAK classification postoperatively. Restoration was most frequently observed in knees with a neutral JLO. Among the subgroups, CPAK type VI showed the highest restoration rate (75%), followed by type V (60%) and type IV (45%); the distribution of the remaining types is presented in **Figure 5**. The preoperative and postoperative radiographic parameters according to CPAK classification are presented in **Table 2 and 3**.

The mean follow-up durations were 1.48 ± 0.97 years and 1.43 ± 0.96 years for the restored and non-restored preoperative CPAK classification groups, respectively. No significant differences in postoperative ROM were observed between the two groups (flexion: 115° vs. 110° , $p = 0.445$; extension: 5° vs. 5° , $p = 0.770$). The complete case analysis comparing

Table 1 Patients' Demographic Characteristics

Parameters	Values
Mean age, years (SD)	68.5 (5.1)
Gender	
Female, % (n)	82.5% (118)
Side	
Right, % (n)	48.4% (94)
Mean BMI, kg/m ² (SD)	26.5 (3.8)
Kellgren–Lawrence classification	
2, % (n)	14.5% (28)
3, % (n)	54.1% (105)
4, % (n)	31.4% (61)
Prosthesis design	
PFC sigma	90.2% (175)
Triathlon	9.8% (19)

Abbreviations: BMI, body mass index; kg, kilograms; m², square meter; n, number; PFC, press fit condylar; SD, standard deviation

WOMAC scores included 9 patients in the restored group and 34 in the non-restored group. Imputation was not performed for missing data. No significant difference in the mean WOMAC scores was observed between the two groups (13.56 ± 9.58 vs. 18.12 ± 10.64 ; $p = 0.251$). Postoperative complications occurred in 13 (5.7%) patients in the non-restored group,

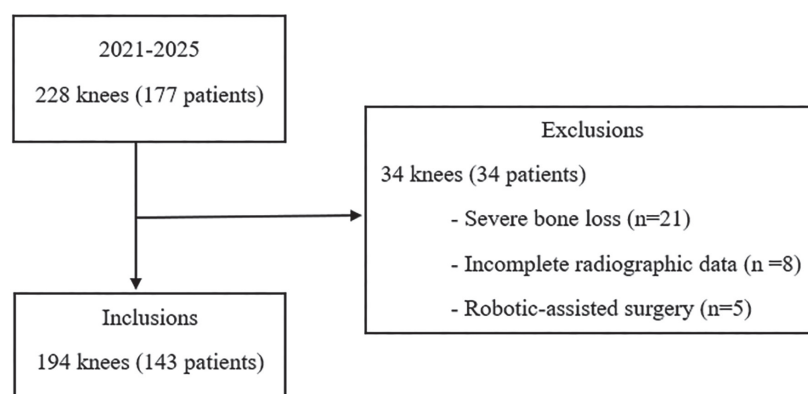


Figure 2 Study Flowchart

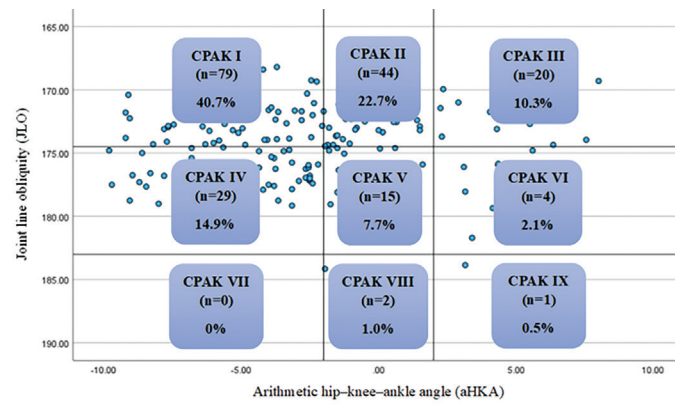


Figure 3 Preoperative CPAK Classification

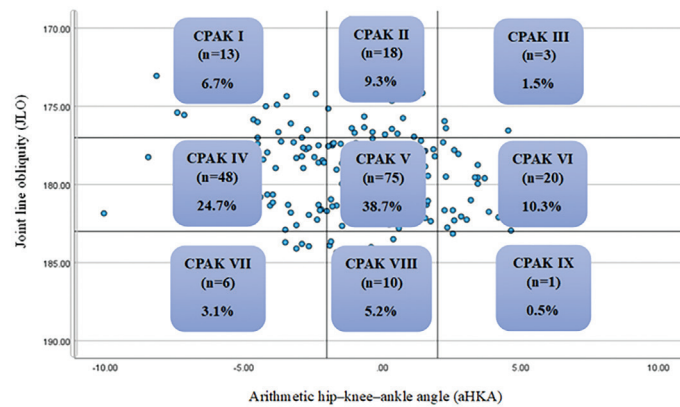


Figure 4 Postoperative CPAK Classification After MA TKA

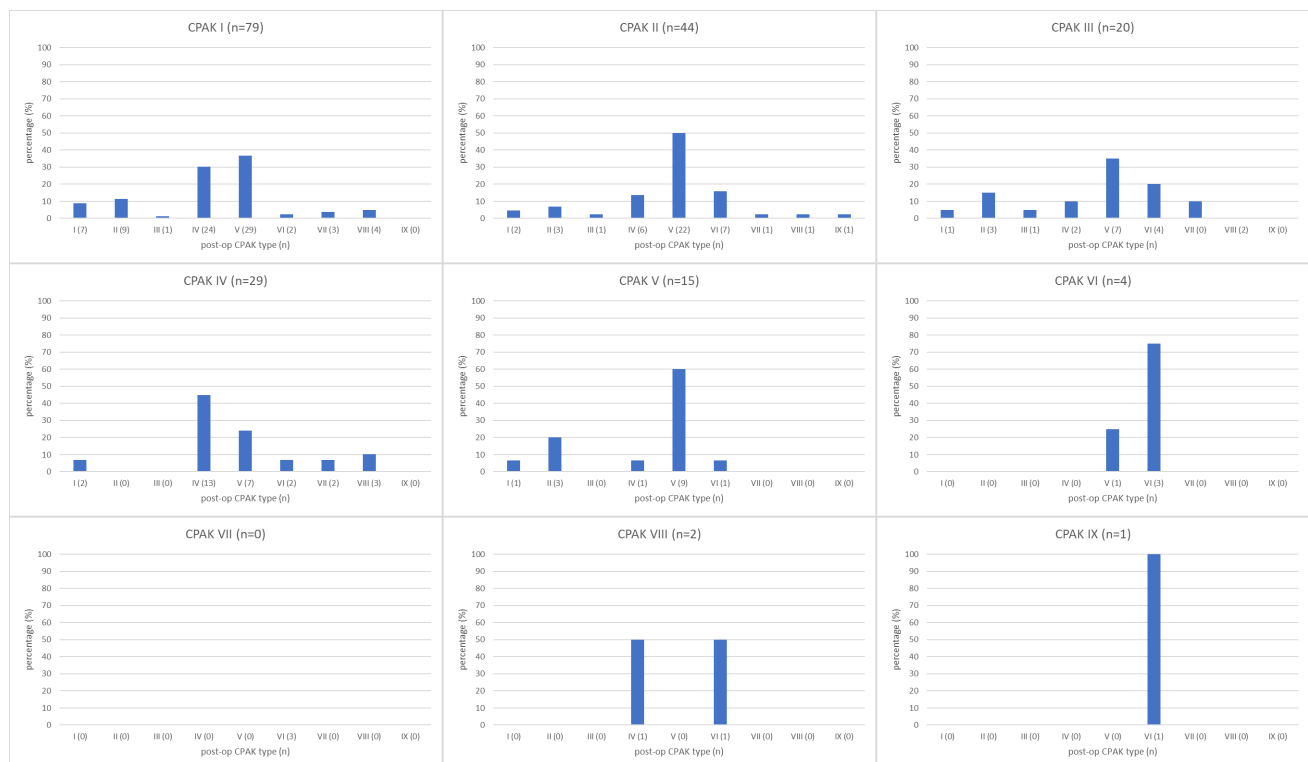


Figure 5 Postoperative CPAK Classification After MA TKA According to the Preoperative CPAK Classification

Table 2 Preoperative Radiographic Parameters According to CPAK Classification

	Mean LDFA ° (SD)	Mean MPTA ° (SD)	Mean JLO ° (SD)	Mean aHKA ° (SD)
CPAK I (n = 79)	89.39 (1.88)	83.95 (1.64)	173.34 (2.32)	−5.44 (2.67)
CPAK II (n = 44)	86.66 (1.40)	86.23 (1.12)	172.89 (2.30)	−0.44 (1.07)
CPAK III (n = 20)	83.64 (1.95)	88.87 (1.83)	172.51 (2.69)	5.23 (2.66)
CPAK IV (n = 29)	92.42 (2.45)	86.14 (1.78)	178.56 (1.53)	−6.27 (4.00)
CPAK V (n = 15)	89.39 (0.60)	89.33 (0.58)	178.72 (0.80)	−0.06 (0.86)
CPAK VI (n = 4)	87.68 (1.10)	91.63 (0.80)	179.31 (1.70)	3.96 (0.90)
CPAK VII (n = 0)	0	0	0	0
CPAK VIII (n = 2)	92.90 (0.21)	91.58 (0.67)	184.48 (0.46)	−1.33 (0.88)
CPAK IX (n = 1)	90.35 (n/a)	93.5 (n/a)	183.85 (n/a)	3.15 (n/a)

Abbreviations: SD, standard deviation; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle; JLO, joint line obliquity; aHKA, arithmetic hip–knee–ankle; CPAK, coronal plane alignment of the knee

Table 3 Postoperative Radiographic Parameters According to CPAK Classification

	Mean LDFA ° (SD)	Mean MPTA ° (SD)	Mean JLO ° (SD)	Mean aHKA ° (SD)
CPAK I (n = 13)	89.96 (0.88)	85.19 (1.29)	175.15 (1.13)	−4.77 (1.90)
CPAK II (n = 18)	87.79 (0.88)	87.47 (1.13)	175.26 (1.80)	−0.32 (0.92)
CPAK III (n = 3)	86.63 (0.56)	89.67 (0.78)	176.30 (0.31)	3.03 (1.31)
CPAK IV (n = 48)	91.82 (1.28)	87.69 (1.24)	179.51 (1.82)	−4.13 (1.74)
CPAK V (n = 75)	89.87 (0.98)	89.76 (1.02)	179.63 (1.61)	−0.11 (1.19)
CPAK VI (n = 20)	88.62 (0.98)	91.8 (1.02)	180.42 (1.83)	3.18 (0.78)
CPAK VII (n = 6)	94.38 (1.64)	91.00 (1.68)	185.39 (3.22)	−3.38 (0.84)
CPAK VIII (n = 10)	92.61 (0.75)	91.94 (0.75)	184.55 (1.03)	−0.68 (1.09)
CPAK IX (n = 1)	90.3 (n/a)	92.85 (n/a)	183.15 (n/a)	2.55 (n/a)

Abbreviations: SD, standard deviation; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle; JLO, joint line obliquity; aHKA, arithmetic hip–knee–ankle; CPAK, coronal plane alignment of the knee

including postoperative stiffness (n = 4), periprosthetic joint infection (n = 4), secondary patellar resurfacing (n = 3), anterior knee pain (n = 1), and intraoperative tibial fracture (n = 1). Conversely, one minor superficial wound complication (2.7%) was reported in the restored group.

DISCUSSION

In this study, 81.4% of knees in patients undergoing MA TKA exhibited postoperative alterations in the CPAK classification. Although conventional instrumentation aims to achieve CPAK type V (neutral aHKA and JLO), its inherent imprecision can result in unintended alignment outcomes, including non-type V phenotypes and, in some cases, incidental restoration of the preoperative

CPAK classification. In the present cohort, however, the rate of such restoration was low.

The observed rate of CPAK alteration was slightly higher than that reported by Corban et al., in which 75.3% of knees demonstrated a change in CPAK classification after MA TKA using conventional instrumentation.¹⁵ This discrepancy may reflect population-related differences. Their cohort comprised a non-Asian population, in which CPAK type V is more prevalent, whereas Asian populations tend to exhibit constitutional varus alignment. In the original study by Macdessi et al., CPAK type II was the most common phenotype (32.2%), while type V accounted for 14.6% in an arthritic population.¹⁰ In contrast, CPAK type I was the most prevalent in our cohort (40.7%), and only 7.7% of knees were classified as type V preoperatively. Similarly, a recent study of Thai patients with knee OA reported type I as the most common phenotype (49.3%), with a low prevalence of type V (6.5%).¹¹

Another possible explanation is that only 38.7% of knees in our study achieved CPAK type V postoperatively, which is the intended alignment target of MA TKA. This inaccuracy may be due to the limitations of conventional instrumentation, particularly when performing frontal cuts on the distal femur and proximal tibia, which can cause deviation from the intended neutral alignment.^{16,17}

Notably, this study demonstrates that knees with a preoperative neutral joint line (CPAK type IV, V, VI) were more likely to return to their original CPAK classification after MA TKA, consistent with the findings of Corban et al.¹⁵ In MA TKA, both LDFA and MPTA are typically targeted at 90°. However, the accuracy of coronal bone cuts using conventional instrumentation is generally within $\pm 3^\circ$ in most cases.¹⁸ Consequently, small variations in the relative difference between MPTA and LDFA can readily produce alignment within CPAK types IV, V, and VI. In contrast, larger and more directional deviations are required to shift alignment into other CPAK phenotypes, which may explain their lower probability of occurrence.

Although comparisons between preoperative and postoperative CPAK classifications showed that only a small proportion of knees in our cohort were restored to their original phenotype, no significant differences in ROM or WOMAC scores were observed between the restored and non-restored groups. These findings should be interpreted with caution, as the uneven distribution of cases, with a predominance of non-restored knees,

may have introduced bias.

A previous randomized controlled trial comparing 180 patients with restored and non-restored CPAK classification after TKA found no significant differences in any patient-reported outcomes (PROMs) between the two groups 1 year postoperatively. However, patients in the non-restored CPAK group tended to require more soft-tissue release.¹⁹ Similarly, in Bertugli et al.'s retrospective study involving 201 patients, no significant differences in PROMs after TKA were observed between patients with restored and non-restored CPAK classification. Additionally, they reported similar mean postoperative satisfaction levels between the two groups (4.4 ± 1.1 vs. 4.4 ± 1.0).²⁰ Conversely, Konishi et al. investigated the impact of alterations in the CPAK classification after TKA and reported that patients whose alignment shifted from varus to valgus and vice versa and who developed apex-proximal JLO postoperatively demonstrated poorer PROMs.⁸ Therefore, restoring CPAK classification may not be essential for achieving satisfactory outcomes, as long as mechanical stability and soft-tissue balance are maintained. However, further studies are needed to clarify the influence of alterations in the CPAK classification on long-term clinical outcomes.

This study has several limitations. First, the retrospective nature of this study may introduce an inherent selection bias and limits control over potential confounding factors that may affect the outcomes. However, all eligible patients were consecutively enrolled in this study to minimize this potential bias. Second, radiographic measurements were performed by a single observer. Although intraobserver reliability was good to excellent, this approach may introduce measurement bias and does not allow for the assessment of interobserver reliability. Third, a substantial proportion of patients had missing WOMAC data, representing an important limitation. Consequently, a complete-case analysis was performed, which may introduce selection bias and reduce statistical power. Fourth, no standardized protocol was used for clinical outcome assessment; therefore, data from the most recent follow-up were used, which may affect the comparability of outcomes. Finally, the follow-up duration was relatively short, which limits the ability to assess long-term outcomes. Further prospective studies with longer follow-up and rigorous methodologies are needed to investigate the significance of alterations in the CPAK classification after TKA.

CONCLUSION

A fixed MA TKA target may alter CPAK classification postoperatively, with only a limited proportion of patients restoring their original CPAK classification. However, no significant differences in clinical outcomes were observed between patients who restored their CPAK classification and those who did not.

Conflict of Interest

The authors declare no conflicts of interest related to the content of this article.

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The authors have no acknowledgments. Furthermore, the authors did not use artificial intelligence (AI) in the preparation of this manuscript.

Author Contributions

Conceptualization: P.W., I.O.

Data curation: P.W., N.H.

Formal analysis: P.W., I.O.

Funding acquisition: -

Investigation: P.W., N.H.

Methodology: P.W., I.O.

Project administration: P.W., I.O.

Resources: P.W.

Software: P.W.

Supervision: I.O.

Validation: N.H., I.O.

Visualization: P.W.

Writing – original draft preparation: P.W.

Writing – review & editing: P.W., N.H., I.O.

Data availability statement

The datasets used and/or analyzed in this study are available from the corresponding author upon reasonable request.

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