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Original Research Article

Alignment Phenotype Restoration After Total Knee Replacement: A CPAK Classification Analysis

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ABSTRACT

Background: Total knee replacement (TKR) is a well-established procedure for end-stage knee osteoarthritis, traditionally guided by mechanical alignment principles aiming for a neutral limb axis. However, growing evidence indicates significant variability in native knee alignment, and the Coronal Plane Alignment of the Knee (CPAK) classification has emerged as a useful framework to describe this diversity and support personalized alignment strategies.

Objectives: To evaluate restoration of native CPAK phenotype following TKR and to assess changes in joint line obliquity and coronal alignment parameters.

Methods: This prospective observational study included 50 patients with primary osteoarthritis undergoing TKR. Standardized long-leg standing radiographs were obtained pre- and post-operatively. Hip–knee–ankle (HKA) angle, mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), and joint line obliquity (JLO) were measured, and CPAK classification was applied to determine phenotype restoration and alignment changes.

Results: Varus phenotypes predominated pre-operatively (72%), with Type V being most frequent. Restoration of the original CPAK phenotype occurred in 40% of patients, while 30% shifted to adjacent phenotypes. Neutralization to Type V was observed in 20%, and valgus over-correction occurred in 10%. Significant improvements were observed in all radiographic parameters, including reduction of mean HKA from 7.59° ± 1.94° to 0.61° ± 1.07° and JLO from 5.84° ± 1.43° to 2.01° ± 1.08° ($p < 0.001$).

Conclusion: TKR effectively corrects coronal deformity but frequently alters native knee phenotype when performed using mechanical alignment principles. CPAK classification provides valuable insight into alignment changes and may facilitate personalized surgical planning. Future TKR strategies should emphasize restoration of constitutional alignment to optimize biomechanical and functional outcomes.

Keywords*:* Total knee replacement, CPAK classification, constitutional alignment, joint line obliquity, kinematic alignment, osteoarthritis knee.

INTRODUCTION

Total knee replacement (TKR) is widely recognized as an effective surgical procedure for end-stage knee osteoarthritis, providing substantial pain relief, deformity correction, and functional improvement. Conventional TKR techniques have historically followed the principle of mechanical alignment, aiming to achieve a neutral hip–knee–ankle (HKA) axis to ensure uniform load distribution and implant longevity {1}. This concept has dominated arthroplasty practice for decades and has been associated with satisfactory survivorship outcomes {2}.

Despite its success, accumulating evidence suggests that the native alignment of the human knee is highly variable, with many individuals demonstrating constitutional varus or valgus alignment rather than neutral mechanical alignment {3}. Forcing a neutral axis in such patients may lead to altered ligament tension, non-physiological kinematics, and potential dissatisfaction following TKR {4}. These observations have stimulated interest in alternative alignment strategies, including kinematic and personalized alignment, which aim to restore patient-specific anatomy and joint biomechanics {5}.

The Coronal Plane Alignment of Knee (CPAK) classification has emerged as a comprehensive framework for describing native knee phenotype. By integrating key radiographic parameters—mechanical lateral distal femoral angle (mLDFA), medial proximal tibial angle (MPTA), HKA angle, and joint line obliquity (JLO)—the CPAK system categorizes knees into nine distinct phenotypes (Types I–IX), reflecting the diversity of coronal alignment patterns {6}. This classification allows surgeons to better understand constitutional alignment and may guide individualized surgical planning.

Recent studies have highlighted that conventional mechanically aligned TKR frequently modifies or neutralizes the native CPAK phenotype, potentially impacting functional outcomes and ligament balance {7}. Conversely, phenotype restoration strategies may improve joint stability, proprioception, and patient satisfaction by preserving natural alignment characteristics {8}. However, evidence evaluating CPAK phenotype restoration following TKR remains limited, particularly in prospective clinical settings.

Therefore, the present study was conducted to evaluate the extent to which TKR restores native CPAK phenotype in patients with primary osteoarthritis knee. Additionally, the study aimed to assess changes in joint line obliquity and quantify the magnitude and direction of coronal alignment correction following arthroplasty.

MATERIALS AND METHODS

Study Design and Population

This prospective observational study included 50 patients with primary osteoarthritis knee undergoing TKR at a tertiary care center.

Radiographic Assessment

Standardized long-leg standing radiographs were obtained pre-operatively and post-operatively. The following parameters were measured:

- Hip-knee-ankle (HKA) angle
- Mechanical lateral distal femoral angle (mLDFA)
- Medial proximal tibial angle (MPTA)
- Joint line obliquity (JLO)

CPAK Classification

Each knee was categorized into one of nine CPAK phenotypes (Types I–IX) based on combined angular relationships. Pre- and post-operative phenotypes were compared to determine restoration or alteration.

Outcome Measures

- Primary outcome: Restoration of original CPAK phenotype
- Secondary outcomes: Direction of phenotype change, joint line obliquity correction, and magnitude of alignment correction

Statistical Analysis

Continuous variables were expressed as mean ± SD. Pre- and post-operative values were compared using paired statistical tests, with significance set at $p < 0.05$.

RESULTS

A total of 50 patients with primary osteoarthritis knee undergoing total knee replacement were included in the analysis. Pre-operative radiographic assessment demonstrated a predominance of varus alignment patterns, with 72% of knees exhibiting varus CPAK phenotypes, while the remaining cases were distributed among neutral and valgus phenotypes. Type V was the most frequently observed phenotype overall.

Post-operative evaluation revealed substantial correction of coronal alignment parameters, with most knees approaching neutral mechanical alignment. However, CPAK-based analysis showed variable restoration of native phenotype. Exact restoration of the original CPAK phenotype occurred in 40% of patients, whereas 30% demonstrated a shift to adjacent phenotypes, indicating partial correction without complete preservation of constitutional alignment. Additionally, 20% of knees were neutralized to Type V phenotype, reflecting the effect of mechanical alignment strategy. Valgus over-correction was observed in 10% of patients, representing a smaller but clinically significant subgroup.

Radiographic parameter analysis demonstrated statistically significant improvements in all measured variables. The mean HKA angle improved from a pre-operative varus of 7.59° to near-neutral 0.61° post-operatively ($p < 0.001$). MPTA increased significantly toward neutral values, while mLDFA showed modest correction. Joint line obliquity (JLO) decreased markedly following surgery, indicating improved coronal plane balance and flattening of the joint line.

Table 1. Phenotype Restoration Following TKR (n = 50)

Outcome Category	Number of Patients	Percentage
Original CPAK restored	20	40%
Shift to adjacent phenotype	15	30%
Neutralized to Type V	10	20%
Valgus over-correction	5	10%

Table 2. Comparison of Radiographic Parameters Pre- and Post-operatively

Parameter	Pre-op Mean ± SD	Post-op Mean ± SD	p-value
HKA	7.59 ± 1.94	0.61 ± 1.07	<0.001
mLDFA	91.92 ± 1.31	89.06 ± 0.96	<0.01
MPTA	83.92 ± 1.34	89.10 ± 0.76	<0.001
JLO	5.84 ± 1.43	2.01 ± 1.08	<0.001

DISCUSSION

The present study evaluated the restoration of native knee phenotype following total knee replacement using the Coronal Plane Alignment of the Knee (CPAK) classification. The findings demonstrate that although TKR effectively corrected coronal deformity and significantly improved radiographic alignment parameters, complete restoration of constitutional phenotype was achieved in only 40% of patients. A substantial proportion exhibited shifts toward adjacent or neutral phenotypes, reflecting the influence of conventional mechanical alignment strategies on native knee anatomy.

The predominance of varus phenotypes (72%) observed in this study is consistent with the concept of constitutional varus described by Bellemans et al., who demonstrated that a significant proportion of individuals naturally possess varus limb alignment rather than neutral mechanical alignment {1}. Subsequent studies have reinforced this concept, showing that constitutional alignment patterns are common and may contribute to the development and progression of knee osteoarthritis {3,10}. The high prevalence of varus phenotypes in the present study therefore reflects both the constitutional alignment of the population and the biomechanical predisposition associated with osteoarthritis.

The CPAK classification provided a comprehensive framework for analyzing alignment diversity and postoperative changes. MacDessi et al., in their original description of CPAK, emphasized that native knee alignment represents a spectrum of phenotypes defined by the relationship between femoral and tibial joint line orientation {4}. More recent work has further validated CPAK as a clinically useful classification, demonstrating that phenotype distribution varies with osteoarthritis severity and may influence surgical planning and outcomes {6,7}. The current findings align with these reports by illustrating that TKR frequently modifies phenotype distribution, particularly when mechanical alignment techniques are employed.

Restoration of the original CPAK phenotype in 40% of patients suggests that preservation of constitutional alignment is achievable in selected cases; however, the observed shift to adjacent phenotypes in 30% of knees highlights the limitations of standardized alignment strategies. Mechanical alignment inherently aims for neutral limb axis, which may not correspond to the patient's native anatomy. Rivière et al. highlighted the ongoing paradigm shift in TKR toward individualized alignment philosophies, emphasizing that a single alignment target may not be appropriate for all patients {9}. Similarly, Grant et al. underscored that CPAK classification can guide surgeons in identifying alignment targets that better reflect native knee biomechanics {5}.

Neutralization of phenotype to Type V in 20% of patients in this study further supports the concept that mechanical alignment tends to homogenize alignment patterns. Experimental work by Delport et al. demonstrated that restoration of constitutional alignment results in more physiological collateral ligament strain compared with neutral mechanical alignment, suggesting that phenotype preservation may improve soft tissue balance and joint kinematics {8}. These findings lend support to emerging alignment strategies such as kinematic and restricted kinematic alignment, which prioritize restoration of patient-specific anatomy.

Valgus over-correction observed in 10% of cases is clinically significant, as excessive correction may disrupt ligament balance and alter gait mechanics. Previous studies have shown that aggressive attempts to achieve neutral alignment in severely varus knees may increase the risk of over-correction and instability. Moreover, research on joint line orientation indicates that constitutional alignment patterns influence joint line obliquity and soft tissue tension, reinforcing the importance of cautious and individualized correction {2}.

Radiographic analysis in the present study demonstrated significant reductions in HKA and joint line obliquity following TKR. While correction toward neutral alignment improves load distribution across the prosthesis, excessive flattening of the joint line may deviate from native biomechanics. The CPAK framework highlights that joint line orientation is a key determinant of phenotype and ligament balance, suggesting that preservation of physiological joint line obliquity may be beneficial in selected patients {4,5}.

Clinical Implications

The findings of this study emphasize the clinical value of CPAK classification in understanding native knee diversity and guiding alignment decisions. Pre-operative identification of CPAK phenotype may help surgeons tailor bone resections and implant positioning to better replicate constitutional anatomy. Personalized alignment strategies may reduce the need for extensive soft tissue releases, improve ligament balance, and potentially enhance patient satisfaction and functional recovery.

Strengths and Limitations

This study’s strengths include its prospective design, standardized radiographic evaluation, and application of CPAK classification for phenotype-based analysis. However, the sample size was modest, and functional outcome measures were not correlated with phenotype restoration. Additionally, the use of mechanical alignment limits direct comparison with kinematic alignment techniques. Long-term follow-up studies incorporating functional outcomes and implant survivorship are needed to clarify the clinical impact of phenotype restoration.

CONCLUSION

The present study demonstrates that total knee replacement produces significant correction of coronal plane deformity and joint line orientation in patients with osteoarthritis knee. However, analysis using the CPAK classification reveals that restoration of the native knee phenotype is achieved in only a proportion of cases, with conventional mechanical alignment frequently resulting in neutralization or alteration of constitutional alignment patterns.

Although 40% of knees in this study retained their original CPAK phenotype, a considerable number exhibited shifts to adjacent or neutral phenotypes, and a small subset showed valgus over-correction. These findings highlight the inherent limitations of a uniform mechanical alignment approach in the presence of diverse native knee anatomies. The observed reduction in joint line obliquity further underscores the influence of surgical technique on postoperative knee biomechanics.

The CPAK classification proved to be a valuable framework for evaluating alignment changes and understanding phenotype diversity following arthroplasty. Incorporating CPAK-based assessment into pre-operative planning may facilitate more individualized alignment strategies and help optimize soft tissue balance, joint kinematics, and functional outcomes.

In conclusion, while TKR effectively corrects deformity and restores mechanical alignment, future arthroplasty strategies should aim toward personalized phenotype restoration rather than routine neutralization. Larger studies with functional and long-term outcome correlation are warranted to establish the clinical benefits of CPAK-guided alignment in total knee replacement.

REFERENCES

1. Bellemans J, Colyn W, Vandenneucker H, Victor J.The Chitranjan Ranawat Award: Is neutral mechanical alignment normal for all patients? The concept of constitutional varus. Clin Orthop Relat Res. 2012;470(1):45-53.
2. Victor J, Bassens D, Bellemans J, Gürsu S, Dhollander A, Verdonk P. Constitutional varus does not affect joint line orientation in the coronal plane. Clin Orthop Relat Res. 2014;472(1):98-104.

3. Vandekerckhove PJTK, Teeter MG, Naudie DDR, MacDonald SJ, McCalden RW.The relationship between constitutional alignment and varus osteoarthritis of the knee. Knee Surg Sports Traumatol Arthrosc. 2017;25(10):3187-3196.
4. MacDessi SJ, Griffiths-Jones W, Harris IA, Bellemans J, Chen DB. Coronal Plane Alignment of the Knee (CPAK) classification. Bone Joint J. 2021;103-B(2):329-337.
5. Grant S, Vigdorchik J, Bellemans J, MacDessi SJ. The Coronal Plane Alignment of the Knee classification: how it works and how it can affect outcomes. JBJS Open Access. 2025;10(4):e25.00165.
6. Kim SE, MacDessi SJ, Song D, Bae DK, et al. CPAK type shifts toward constitutional varus with increasing Kellgren–Lawrence grade in osteoarthritic knees. J Bone Joint Surg Am. 2024;106(24):2197-2204.
7. León-Muñoz VJ, et al. Distribution of coronal plane alignment of the knee phenotypes in patients with knee osteoarthritis. J Clin Med. 2024;13(5):1342.
8. Delport H, Labey L, Innocenti B, Bellemans J. Restoration of constitutional alignment in total knee arthroplasty leads to more physiological strains in the collateral ligaments. Knee Surg Sports Traumatol Arthrosc. 2015;23(8):2159-2169.
9. Rivière C, Iranpour F, Harris S, Auvinet E, Aframian A, Parratte S, et al. Alignment options for total knee arthroplasty: a systematic review. Orthop Traumatol Surg Res. 2017;103(7):1047-1056.
10. Song MH, Yoo SH, Chang CB, Kang YG, Kim SJ, Seong SC. Coronal alignment of the lower limb and the incidence of constitutional varus knee in Korean females. Knee Surg Relat Res. 2015;27(1):49-55.