Mechanical Alignment in Total Knee Arthroplasty: A Coronal Plane Alignment of the Knee (CPAK) Analysis

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INTRODUCTION: The Coronal Plane Alignment of the Knee (CPAK) classification provides a comprehensive framework to describe coronal alignment in TKA, incorporating both arithmetic hip-knee-ankle (aHKA) and joint line obliquity (JLO). Mechanical alignment (MA) aims to achieve CPAK Type V, defined by neutral aHKA and neutral JLO, but is not consistently achieved in practice. Only 25–60% of TKAs reach the intended neutral CPAK phenotype postoperatively, suggesting variability due to patient factors and surgical technique. Moreover, while mechanical alignment is widely practiced, the clinical value of achieving neutral alignment is still under investigation. This study aims (1) to characterize the postoperative distribution of CPAK phenotypes following the target of MA-TKA across the three different surgical technologies, and (2) to investigate whether achieving mechanical alignment targets is associated with improved patient-reported outcomes.

METHODS: A retrospective review was conducted on 636 primary total knee arthroplasties (TKAs) performed between January 2016 and December 2018 at a single high-volume institution. All procedures were executed using a mechanical alignment strategy, employing either manual, computer-navigated, or robotic techniques. Preoperative and postoperative full-leg standing radiographs were analyzed to calculate the aHKA and JLO, and patients were subsequently classified according to the CPAK system. Patient-reported outcome measurements (PROMs), including Knee Injury and Osteoarthritis Outcome Score Joint Replacement (KOOS JR) and Veterans RAND 12 - Physical Score (VR-12 Physical Score) were recorded pre-operatively and at two years post-operatively. Patients were first stratified by surgical technology, and their postoperative CPAK distributions were compared. Mechanical alignment target was defined to be Type V CPAK according to MacDessi et.al, and neutral JLO and neutral aHKA were assessed separately. The full cohort was then evaluated to determine whether meeting these alignment targets translated into superior patient-reported outcomes. Multivariable logistic analyses were performed to assess how surgical technique and patient characteristics predicted each alignment target, and whether achieving these targets increased the odds of reaching clinically meaningful KOOS-JR thresholds.

RESULTS: No significant difference in demographic and preoperative coronal alignment was observed between the three groups (p = 0.10). The postoperative CPAK distribution was found to be significantly different between the three techniques (p < 0.001), with robotic-assisted TKA reporting a significantly higher proportion of patients meeting the mechanical alignment target (62.9%), compared to manual (48.2%) and computer-navigated (51.2%) (Graph 1). Multivariable regression analysis confirmed the robotic-assisted technique as a significant positive predictor for achieving both neutral JLO (OR=4.3, 95% CI [2.33–8.41], p<0.001) and CPAK Type V (OR=2.25, 95% CI [1.47–3.45], p<0.001) (Table 1). Postoperative neutral alignment did not statistically increase KOOS-JR or VR-12 Physical scores at two years compared to patients who did not achieve the target (p > 0.05) (Table 2). Multivariable analysis confirmed that none of the alignment targets independently increased the odds of meeting KOOS-JR clinical thresholds (p > 0.26).

DISCUSSION AND CONCLUSION: While utilizing the same mechanical alignment philosophy, the postoperative CPAK distribution varies significantly by surgical technique, with robotic-assisted TKA associated with a higher rate of achieving the mechanical alignment target. However, achieving the mechanical alignment target does not appear to confer a significant improvement in postoperative functional outcomes. These findings question the value of a one-size-fits-all alignment philosophy and support a more individualized strategy by integrating phenotype-based classifications with advanced surgical technologies.

Graph 1.

Postoperative Coronal Plane Alignment of the Knee (CPAK) Phenotype Distribution Across Surgical Technologies. aHKA, arithmetic hip-knee-ankle angle; JLO, joint line obliquity; LDFA, lateral distal femoral angle; MPTA, medial proximal tibial angle.

Table 1. Multivariable logistic regression identifying factors associated with achieving neutral aHKA, neutral JLO, and postoperative CPAK Type V phenotype. aHKA: arithmetic Hip-Knee-Ankle angle; JLO: Joint Line Obliquity; CPAK: Coronal Plane Alignment of the Knee; CI: Confidence Interval; BMI: Body Mass Index.

Outcome	Factor	Reference / Comparison	Odds Ratio (95% CI)	p-value
Neutral aHKA	Surgical technique	Robotic vs Manual	1.43 [0.92 – 2.24]	0.115
		Computer Nav. vs Manual	1.23 [0.81 – 1.86]	0.336
	Year of surgery	2017 vs 2016	1.17 [0.51 – 2.59]	0.71
		2018 vs 2016	1.40 [0.62 – 3.02]	0.406
	Age (per year)	—	1.00 [0.98 – 1.03]	0.798
	Sex	Male vs Female	1.47 [1.05 – 2.08]	<0.03
	BMI (per unit)	—	1.02 [0.99 – 1.05]	0.54
Neutral JLO	Surgical technique	Robotic vs Manual	4.30 [2.33 – 8.41]	<0.001
		Computer Nav. vs Manual	0.95 [0.61 – 1.47]	0.804
	Year of surgery	2017 vs 2016	1.81 [0.54 – 5.14]	0.502
		2018 vs 2016	1.92 [0.58 – 5.50]	0.247
	Age (per year)	—	1.00 [0.97 – 1.03]	0.960
	Sex	Male vs Female	0.73 [0.47 – 1.07]	0.101
	BMI (per unit)	—	1.04 [1.01 – 1.07]	<0.05
Type V CPAK	Surgical technique	Robotic vs Manual	2.25 [1.47 – 3.45]	<0.001
		Computer Nav. vs Manual	1.26 [0.85 – 1.86]	0.246
	Year of surgery	2017 vs 2016	1.25 [0.56 – 2.73]	0.574
		2018 vs 2016	1.24 [0.57 – 2.64]	0.584
	Age (per year)	—	1.01 [0.99 – 1.03]	0.555
	Sex	Male vs Female	1.17 [0.85 – 1.63]	0.336
	BMI (per unit)	—	1.04 [1.00 – 1.06]	<0.05

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Table 2. Comparison of Patient-reported outcome measurement (PROMs) between patients who achieved versus did not achieve the postoperative alignment targets. KOOS JR: Knee Injury and Osteoarthritis Outcome Score Joint Replacement; VR-12: Veterans RAND-12 – Physical Score; N: Number of patients; %: Percentage; SD: Standard Deviation.

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