Restoring Constitutional CPAK Phenotype Enhances Early Functional Recovery After Total Knee Arthroplasty: A Prospective In-Office Gait-Analysis Study

Carmelo Burgio[1], MD, Karlos Zepeda[1], DO, MS, Shrey Vachhani[1], BA, Tsion Yared[1], BA, David Mayman[1], MD, Seth Jerabek[1], MD, Peter K. Sculco[1], MD, Fernando Quevedo Gonzalez[1], PhD, Eytan M. Debbi[1], MD, PhD, Jonathan M. Vigdorchik[1], MD

[1]Hospital for Special Surgery, New York, NY

Email of Presenting Author: Burgioc@hss.edu

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INTRODUCTION: Knee osteoarthritis is a leading cause of disability worldwide, and total knee arthroplasty (TKA) remains the most effective treatment when conservative measures fail[1-4]. One of the most debated aspects of TKA is postoperative alignment. Traditional techniques aim for neutral alignment, whereas newer approaches seek to replicate native knee kinematics by restoring each patient's constitutional alignment and preserving the natural joint line[4]. The Coronal Plane Alignment of the Knee (CPAK) classification provides an objective framework for describing alignment, grouping knees into nine phenotypes based on two key parameters: lower limb alignment, defined by the arithmetic hip–knee–ankle angle (aHKA), and joint line obliquity (JLO)[5]. Although restoration of the native phenotype is supported by strong biomechanical evidence, its impact on clinical outcomes remains debated, with most studies relying on subjective patient-reported measures[1-4]. In contrast, gait analysis represents one of the most reliable and objective tools for evaluating lower limb kinematics, offering precise data on postoperative recovery[6-10]. The objective was to determine whether preservation of the CPAK phenotype correlates with superior early postoperative gait recovery. We hypothesized that patients whose preoperative phenotype was restored would demonstrate superior early gait pattern.

METHODS: After approval of an institutional review board, we prospectively enrolled 27 participants who underwent Robotic-Assisted TKA performed by 5 different fellowship-trained orthopedic surgeons. Spatiotemporal gait parameters and joint-level kinematics were evaluated both preoperatively and at six weeks postoperatively using in-office gait assessment tools. Participants walked across the GAITRite® pressure mat, which captured spatiotemporal data reflecting overall gait performance, including measures related to walking speed, support phases, and stride characteristics[7,8]. Joint-specific range of motion was captured using 4DMotion® wearable sensors as participants performed four functional tasks: sit-to-stand, 10-meter ambulation, stair ascent, and stair descent[9-11]. Additional functional assessments included the Timed Up and Go (TUG)[12] test and the Forgotten Joint Score (FJS) questionnaire[13]. Pre- and postoperative EOS images were reviewed to measure lower limb alignment, enabling CPAK classification. ANCOVA was used to compare postoperative gait changes between groups, controlling baseline differences.

RESULTS: Out of the study cohort, 11 patients maintained their preoperative CPAK phenotype, while 16 exhibited a postoperative change. There were no significant demographic differences between groups ($p > 0.05$). At six weeks, patients with preserved CPAK alignment demonstrated significantly more favorable spatiotemporal gait mechanics. Cadence was higher (+0.3 vs –7.7 steps/min; $p = 0.03$), with trends toward greater gait velocity and stride length. Step time was also shorter in this group ($p = 0.04$), supporting improved gait efficiency. Analysis of the gait cycle revealed that the preserved CPAK group spent 4% less of the cycle in double support ($p = 0.03$), a parameter associated with improved dynamic balance and confidence during ambulation. They also demonstrated more efficient unloading from double support (–2.1%; $p = 0.01$) and enhanced single-limb support (+2.7%; $p = 0.02$), suggesting better limb control and stability during stance. Across functional tasks, patients with preserved alignment showed more favorable knee range of motion, particularly during stair ascent (+14.9°, $p = 0.04$) and with a similar trend during stair descent (+11.1°, $p = 0.06$). They also reported higher FJS and demonstrated greater improvement in TUG, although differences did not reach statistical significance.

DISCUSSION: Patients who maintained their native alignment following TKA demonstrated more efficient early gait patterns and greater joint mobility during functional tasks. These findings suggest that preserving constitutional coronal alignment is associated with enhanced early postoperative recovery and supports the biomechanical rationale for restoring patient's constitutional coronal alignment. Larger studies with longer follow-up are needed to confirm these results and determine their long-term clinical relevance.

SIGNIFICANCE/CLINICAL RELEVANCE: This study highlights the clinical importance of preserving native knee alignment during TKA, showing its association with more efficient early gait recovery and improved joint mobility. Objective gait analysis provides compelling evidence that alignment strategy may directly influence functional outcomes, supporting more personalized approaches to knee replacement surgery.

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Table 1. Comparison of Spatiotemporal Gait Parameters Between Patients with and without Postoperative CPAK Phenotype Change. CPAK: Coronal Plane Alignment of the Knee; SE: Standard Error; CI: Confidence Interval.

Parameters	Unchanged CPAK (Mean ± SE)	Changed CPAK (Mean ± SE)	Adjusted Mean Difference (95 % CI)	P-value
Double Supp % Cycle	-2.05 ± 0.76	1.94 ± 1.52	-4.00 (0.47 to 7.53)	**0.03**
Double Supp. Time (sec)	-0.03 ± 0.02	0.08 ± 0.05	-0.11 (0.01 to 0.21)	**0.04**
Double Support Load %GC	-0.62 ± 0.43	1.30 ± 1.04	-1.92 (-0.43 to 4.27)	0.11
Double Support Load Time	-0.01 ± 0.01	0.05 ± 0.03	-0.06 (-0.01 to 0.12)	0.07
Double Support Unload %GC	-1.44 ± 0.45	0.64 ± 0.54	-2.07 (0.62 to 3.53)	**0.01**
Double Support Unload Time	-0.02 ± 0.01	0.03 ± 0.02	-0.05 (0.01 to 0.09)	**0.02**
Single Supp % Cycle	1.18 ± 0.52	-1.50 ± 1.02	2.68 (-5.06 to -0.30)	**0.02**
Single Supp. Time (sec)	0.02 ± 0.01	0.01 ± 0.01	0.01 (-0.05 to 0.03)	0.61
Step Length (cm)	2.61 ± 1.33	-1.88 ± 2.07	4.49 (-9.56 to 0.59)	0.08
Step Time (sec)	-0.00 ± 0.02	0.07 ± 0.03	-0.07 (0.00 to 0.13)	**0.04**
Stride Length (cm)	3.61 ± 2.43	-5.20 ± 4.10	8.82 (-18.68 to 1.04)	0.07

Table 2. Comparison of Changes in Hip and Knee Range of Motion During Functional Tasks Between Patients with and without Postoperative CPAK Phenotype Change. CPAK: Coronal Plane Alignment of the Knee; ROM: Range of Motion; SE: Standard Error; CI: Confidence Interval.

Parameters	Assessment	Unchanged CPAK (mean ± SE)	Changed CPAK (mean ± SE)	Adjusted Mean Difference (95 % CI)	P-value
Hip ROM (°)	Sit-to-Stand	-7.2 ± 11.3	15.2 ± 12.8	22.4 (-11.1 to 55.9)	0.21
Knee ROM (°)	Sit-to-Stand	-4.1 ± 4.9	-8.2 ± 2.7	-4.1 (-15.2 to 6.9)	0.47
Hip ROM (°)	Walking	-5.1 ± 6.0	2.8 ± 6.0	7.9 (-8.8 to 24.5)	0.36
Knee ROM (°)	Walking	-2.7 ± 3.4	-3.8 ± 2.7	-1.0 (-9.5 to 7.4)	0.81
Hip ROM (°)	Stairs Up	-2.7 ± 9.2	3.1 ± 10.3	5.8 (-21.2 to 32.8)	0.68
Knee ROM (°)	Stairs Up	2.7 ± 5.5	-12.2 ± 3.9	-14.9 (-28.2 to -1.6)	**0.04**
Hip ROM (°)	Stairs Down	-2.9 ± 9.7	3.4 ± 7.6	6.4 (-17.8 to 30.6)	0.61
Knee ROM (°)	Stairs Down	-2.1 ± 4.6	-13.2 ± 3.2	-11.1 (-22.0 to -0.2)	0.06

Table 3. Functional Outcomes and Gait Performance Preoperatively and at 6 Weeks in Patients with and without Postoperative CPAK Phenotype Change. CPAK: Coronal Plane Alignment of the Knee; FJS-12: Forgotten Joint Score; SE: Standard Error

Parameters	Assessment	Unchanged CPAK (N = 11)	Changed CPAK (N = 16)	P-value
6W FJS-12 Score (mean ± SE)	6W Postop	27.0 ± 4.6	18.9 ± 2.8	0.12
Velocity (cm/sec)	Preop	104.4 ± 7.2	95.1 ± 3.7	
	6W Postop	106.7 ± 6.2	85.9 ± 6.1	
	Delta	2.3 ± 4.3	-9.2 ± 3.9	0.06
Cadence (steps/min)	Preop	99.7 ± 3.4	99.1 ± 2.0	
	6W Postop	99.4 ± 3.5	91.4 ± 2.8	
	Delta	0.3 ± 2.5	-7.7 ± 2.2	**0.03**
Time UP & GO (s)	Preop	5.7 ± 0.5	5.8 ± 0.3	
	6W Postop	4.9 ± 0.4	5.9 ± 0.3	
	Delta	0.8 ± 0.3	0.1 ± 0.25	0.08