RESEARCH ARTICLE

Predictors of Lower Limb Coronal Malalignment after Conventional Total Knee Arthroplasty Using a Mechanical Alignment Strategy

Sadegh Hasani Satehi, MD; Mohammadreza Razzaghof, MD, MPH; Amirhossein Rahimnia, MD; Seyed Saeed Tamehri Zadeh, MD; Milad Salehi, MD; SM Javad Mortazavi, MD

Research performed at Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran

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Abstract

Objectives: The primary goal of total knee arthroplasty (TKA) is to restore the neutral mechanical axis of the lower limb using mechanical alignment. However, no studies to date have investigated the risk factors of coronal malalignment (CM) following conventional TKA. In this study, we aimed to determine the incidence of post-TKA CM and identify its potential risk factors.

Methods: We retrospectively reviewed all conventional primary TKAs utilizing cemented posterior-stabilized prostheses in our institute from January 2019 to 2022. The following variables were extracted from the Joint Reconstruction Research Center (JRRC) Knee Registry Database: demographics, varus classification, flexion contracture, femoral and tibial bowing, pre- and postoperative Hip-knee-ankle angle (HKAA), mechanical lateral distal femoral angle (LDFA), mechanical medial proximal tibial angle (MPTA), joint-line congruency angle (JLCA), and caput-collum-diaphyseal (CCD) angle. Multiple logistic regression was used to develop a predictive model for post-TKA CM.

Results: Among the 402 TKAs analyzed after exclusions, 172 (42.79%) fell outside the acceptable postoperative HKAA range (180° ± 3°). Of the 17 factors studied, the following were associated with an increased risk of postoperative CM: flexion contracture > 10° (OR = 2.95, P < 0.001), femoral bowing > 4.9° (OR= 1.89, P= 0.006), tibial bowing > 2.2° (OR= 2.00, P= 0.002), preoperative MPTA≤ 85° (OR= 1.68, P= 0.037) or HKAA ≥ 20° varus (OR= 5.07, P= 0.017), preoperative JLCA 4°-10° (OR= 2.49, P= 0.023), and CCD ≤ 131° (OR= 1.62, P= 0.044). The results remained almost consistent even after excluding the extreme HKAA outliers (> ±6° varus and valgus).

Conclusion: In mechanically aligned TKAs, the risk of post-TKA CM can be estimated preoperatively based on specific risk factors (e.g., a 40.5% risk for patients with ≥ 3 risk factors). Identifying higher risks can warn the surgeon to address these factors and perform the TKA with greater precision.

Level of evidence: III

Keywords: Alignment, Coronal malalignment, Hip-knee-ankle axis, Mechanical axis, Predictor, Total knee arthroplasty

Introduction

Total knee arthroplasty (TKA) can be performed using various alignment targets including mechanical, kinematic, anatomical, and functional approaches.[1] Despite the advantages and disadvantages of each method, mechanical alignment remains the most commonly used, likely due to its high feasibility and reproducibility.[2] When choosing this approach, the surgeon's primary goal should be to restore the neutral mechanical axis of the lower limb.[3-5] This is defined as a postoperative mechanical hip-knee-ankle angle (HKAA) of 0°, a mechanical lateral distal femoral angle (LDFA) of 90°, and a medial proximal tibial angle (MPTA) of 90°.[4,6-8]

Most previous studies have considered an HKAA outside the range of 3° varus or valgus as coronal malalignment

Corresponding Author: SM Javad Mortazavi, Joint Reconstruction Research Center, Tehran University of Medical Sciences, Tehran, Iran/ Department of Orthopedic Surgery, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran

Email: smjmort@yahoo.com

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(CM).[9-13] although the incidence of postoperative CM in TKA has been reported in several studies, only a few have investigated the preoperative factors that influence the risk of postoperative CM.[14-17] In computer-navigated TKA, flexion contracture, femoral bowing angle, and the severity of preoperative varus deformity have been reported as risk factors for postoperative mechanical axis outliers.[14,15] However, to our knowledge, no study has assessed the potential risk factors for CM in conventional TKA. Understanding these factors can assist surgeons using the mechanical alignment to restore neutral coronal limb alignment more accurately.

Therefore, we designed this study to determine: (1) the incidence of lower limb CM and malalignment of femoral and tibial components following conventional TKA, (2) the pre- and intraoperative risk factors that predict post-TKA CM, and (3) the risk of post-TKA CM considering each of these factors in a risk assessment model. Utilizing this model, surgeons may reserve the more costly and technically demanding methods such as computer navigation and patient-specific instrumentation, for patients with a high predicted risk of post-TKA CM following conventional TKA.

Materials and Methods

In a retrospective cohort study, we reviewed the medical, radiological, and surgical records of all knees (N=550) that underwent conventional primary TKA using a cemented posterior-stabilized (PS) prosthesis at Imam Khomeini Hospital Complex from January 2019 to 2022. The patients underwent TKA for various etiologies including primary osteoarthritis, rheumatoid arthritis, and hemophilic arthropathy. The exclusion criteria included incomplete baseline data, lack of standard pre- or postoperative three-joint radiographs (123 knees), and TKAs using less or more constrained designs, such as cruciate-retaining or condylar-constrained knee designs (30 knees). Ultimately, we included 402 knees (312 patients) who underwent either unilateral TKA or staged bilateral TKA. In all bilateral cases, the TKAs were staged by at least three months apart. We reviewed the patients' medical and surgical records and extracted the following data: age, sex, body mass index (BMI), comorbidities based on the American Society of Anesthesiologists (ASA) score, etiology of osteoarthritis, varus deformity classification, and the presence of preoperative knee flexion contracture (FC). All data were extracted from the Joint Reconstruction Research Center (JRRC) Knee Registry Database.

Our classification of varus deformity was based on the presence of medial tibial bony defect and lateral knee laxity. We defined the medial defect as a bony defect measuring ≥ 7 mm, identified in the standing anteroposterior (AP) knee radiograph. Lateral laxity was characterized by the presence of lateral knee thrust during walking or a joint-line congruency angle of ≥ 7°. Type 1 varus deformity is characterized by the absence of both medial defect and lateral laxity; Type 2 presents with lateral laxity without any medial defect; Type 3 exhibits a medial defect without lateral laxity; and Type 4 has both a medial defect and lateral laxity.

The study's methodology and ethical considerations were reviewed and approved by the Institutional Review Board of Tehran University of Medical Sciences (IR.TUMS.IKHC.REC.1399.129).

Radiographic Evaluation

According to our institutional protocol for TKA, we obtained a standard standing AP three-joint radiograph (3JR) for each patient both before and after surgery, typically within three months to one year postoperatively. We retrieved pre- and postoperative 3JRs for each patient and measured the following alignment angles: hip-knee-ankle angle (HKAA), joint line congruency angle (JLCA), mechanical lateral distal femoral angle (LDFA), mechanical medial proximal tibial angle (MPTA), femoral bowing, tibial bowing, and caput-collum-diaphyseal (CCD) angle.

HKAA is the angle formed between the mechanical axes of the femur and tibia and is the mainstay to determine the varus and valgus alignment of the lower limb. We report it as a deviation from 180° [Figure 1A]. We define HKAA of 180° ± 3° as neutral coronal limb alignment, while HKAAs that fall outside this range, described as outliers, are classified as CM.[4,6,18]

JLCA is the angle formed between the joint lines of the distal femur and proximal tibia. LDFA represents the lateral angle between the femoral mechanical axis and the distal femoral joint line. MPTA is the medial angle between the tibial mechanical axis and the proximal tibial joint line [Figure 1B].

To measure coronal femoral bowing, we employed the method described by Yau et al. measuring the angle between the anatomical axes of the proximal and distal thirds of the femoral diaphysis on 3JR.[19] Tibial bowing was measured in a similar manner, as the angle between the anatomical axes of the proximal and distal thirds of the tibial diaphysis. CCD angle was measured between the anatomical axis of femoral shaft and femoral neck axis according to Müller method [Figure 1C].[20]

We used preoperative standard AP knee radiographs to classify the varus deformity of the knees. The depth of the proximal tibial medial defect was measured using the method described by Aglietti et al.[21] We performed all radiographic measurements with the mediCAD classic software version 3.5 (Altdorf/Landshut, Germany).

Surgical Technique

All TKAs were performed using a cemented PS design and conventional technique by the senior author. After inflating the tourniquet with the knee in flexion, we performed a medial parapatellar arthrotomy through a midline incision. Following an initial release of the soft tissue, the proximal tibia was exposed and cut perpendicular to its mechanical axis using an extramedullary guide. We used the junction between the medial one-third and lateral two-thirds of the tibial tubercle to determine the correct rotation of the tibial component. We then measured the depth of the tibial defect and addressed it accordingly: defects less than 5 mm were filled with cement, those between 5 mm and 10 mm were augmented with screws and cement, and defects greater than 10 mm received bone grafts. Subsequently, we inserted the femoral intramedullary guide at the intersection of the femoral anatomical axis and the distal femoral joint line. The guide angle for the distal femoral cut was determined by the angle between the anatomical and mechanical femoral axes. The transepicondylar line served as the primary reference for femoral component rotation, although we also considered both the posterior epicondylar line and Whiteside's line as secondary references. We used standard layered wound closure techniques and provided appropriate wound care. The same postoperative rehabilitation protocol was applied to all patients.

Statistical Analysis

We used the Student's *t test* and Chi-squared test to compare continuous and discrete variables between inliers and outliers, respectively. Due to the binary nature of the response variable (i.e., inliers vs. outliers), we utilized a logistic regression model to assess the impact of the covariates on the response. In this analysis, we designated inliers as 0and outliers as 1. The logistic model provided odds ratios (ORs) that quantified the impact of the covariates on the likelihood of a patient being classified as outlier. We performed the analyses using the statistical software Stata version 12, with a significance level set as 0.05.

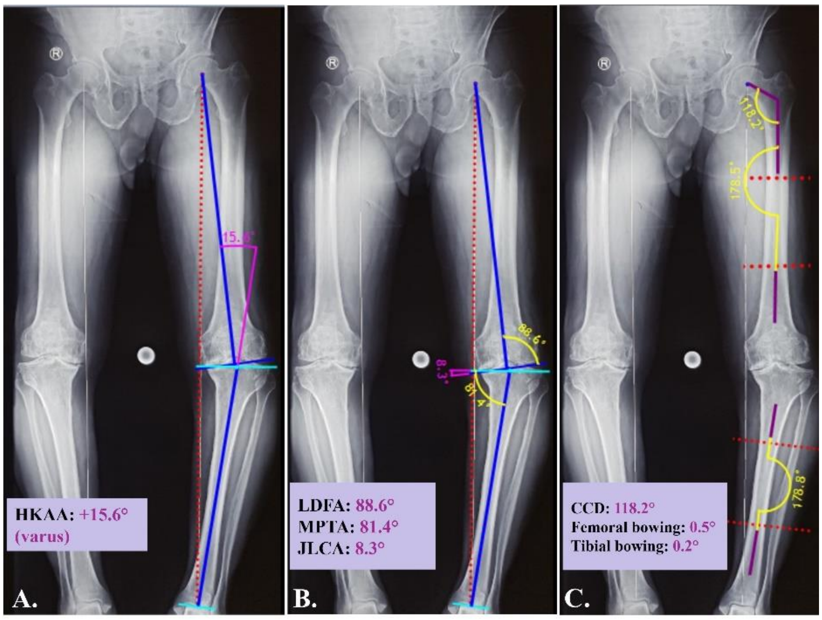

Figure 1. Measurement of HKAA (A); LDFA, MPTA, and JLCA (B); and femoral bowing, tibial bowing, and the CCD angle (C) on standard standing three-joint AP radiograph

Results

A total of 402 knees from 312 patients were included in the study, comprising 222 unilateral and 90 staged TKAs. The average age of the patients was 65 years, with a range from 25 to 89 years. The primary indications for TKA were primary osteoarthritis (n=379), rheumatoid arthritis (n=15), and hemophilia (n=8). Among the knees assessed, there were 383 varus deformity and 19 valgus deformity.

The mean postoperative HKAA was 3.63° (±2.49°). The incidence of postoperative HKAA outliers, defined as values outside the range of 180° ± 3°, was 42.79% (172 knees). The distribution of postoperative HKA axis deviation from 180° is shown in [Figure 2]. The study variables were compared between outliers and inliers of postoperative HKAA [Table 1].

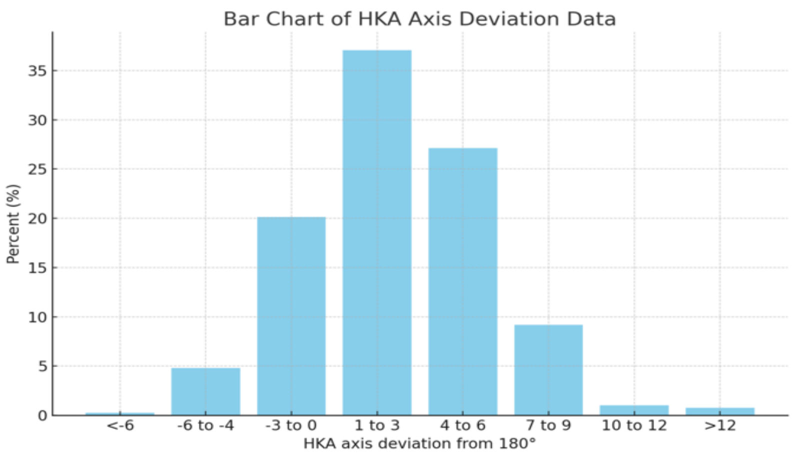

Figure 2. The distribution of postoperative HKAA axis deviation from 180°. A deviation ranging from +3° varus to -3° valgus was considered as acceptable

Table 1. Comparison of variables between the two groups: inliers (postoperative HKAA: 180° ± 3°) and outliers (postoperative HKAA > |180°±3°|).

Variables		Inliers (N = 230)	Outliers (N = 172)	p-value*
Patients' characteristics				
Sex (female), num. (%)	---	185 (80.4 %)	148 (86.05 %)	0.140
Age (yr), mean (SD)	---	65.81 (9.82)	65.39 (9.12)	0.663
≤ 70 vs. > 70	≤ 70, num. (%)	151 (65.65 %)	127 (73.84 %)	0.079
BMI (kg/m2), mean (SD)	---	30.01 (4.51)	30.02 (4.24)	0.982
≤ 30 vs. > 30	≤ 30, num. (%)	121 (52.61 %)	101 (58.72 %)	0.223
ASA score (2), num. (%)	---	86 (37.39 %)	52 (30.23 %)	0.135
Knee Features				
Unilateral, num. (%)	---	173 (75.22 %)	139 (80.81 %)	0.183
	OA	215 (93.48 %)	164 (95.35 %)	---
Diagnosis, num. (%)	*RA*	11 (4.78 %)	4 (2.33 %)	0.387
	Hemophilia	4 (1.74 %)	4 (2.33 %)	---
FC				
≤ 10° vs. > 10°	≤ 10°, num. (%)	183 (79.57 %)	98 (56.98 %)	< 0.001
	1	67 (31.60 %)	47 (28.31 %)	---
	2	100 (47.17 %)	71 (42.77 %)	
Varus type, num. (%)	3	9 (4.25 %)	5 (3.01 %)	0.202
	4	36 (16.98 %)	43 (25.90 %)	---
Preoperative factors				
	Valgus knee	15 (6.5 %)	4 (2.33 %)	---
	0-9° varus	43 (18.70 %)	19 (11.05 %)	
HKAA, num. (%)	*10-19° varus*	130 (56.52 %)	101 (58.72 %)	0.009
	≥ 20° varus	42 (18.26 %)	48 (27.91 %)	---
	≤ 4°	36 (15.65 %)	12 (6.98 %)	---
JLCA, num. (%)	*4-10°*	136 (59.13 %)	119 (69.19 %)	0.020
	> 10°	58 (25.22 %)	41 (23.84 %)	---
LDFA				
≤ 91° vs. > 91°	≤ 91°, num. (%)	125 (54.35 %)	82 (47.67 %)	0.185
MPTA				
≤ 85° vs. > 85°	≤ 85, num. (%)	109 (47.39 %)	114 (66.28 %)	<0.001
Lower limb profile				
Femoral bowing ≤ 4.9° vs. > 4.9°	≤ 4.9°, num. (%)	162 (70.43 %)	96 (55.81 %)	0.002
Tibial bowing ≤ 2.2° vs. > 2.2°	≤ 2.2°, num. (%)	110 (47.83 %)	52 (30.23 %)	<0.001
CCD angle				
≤ 131° vs. > 131°	≤ 131°, num. (%)	143 (62.17 %)	124 (72.09 %)	0.037
Intraoperative factors				
Proximal tibial defect (> 5mm), num. (%)	---	32 (13.91 %)	35 (20.35 %)	0.087
	Nexgen	65 (28.26 %)	70 (40.70 %)	---
	Persona	22 (9.57 %)	10 (5.81 %)	---
Type of prosthesis, num. (%)	Scorpio	42 (18.26 %)	22 (12.79 %)	0.069
	Sigma	21 (9.13 %)	12 (6.98 %)	---
	Triathalon	80 (34.78 %)	58 (33.72 %)	---

*The p-values for continuous and discrete variables were obtained from t-test and chi-squared test, respectively

The mean postoperative alignment angles for the tibial and femoral components were 88.86° (±2.64) and 91.10° (±2.70°), respectively. An alignment angle outside the range of 90° ± 2° was defined as an outlier. Consequently, 147 (37%) of the femoral components and 138 (34%) of the tibial components were identified as outliers. The distribution of femoral and tibial component alignment in relation to the postoperative HKAA is presented in [Table 2]. Notably, the frequency of malalignment in at least one of the femoral or tibial components was 36.52% in TKAs with normal postoperative limb alignment, compared to 87.79% in those with postoperative CM with the difference being statistically significant ($P < 0.05$).

We used a logistic regression model to identify the factors that may significantly influence the response variable, specifically postoperative HKAA. Fitting the univariate logistic models resulted in the OR presented in [Table 3]. We performed these analyses twice; once on the entire dataset and once after excluding the postoperative HKAAs that fell outside the 180° ± 6° range.

Table 2. Postoperative alignment of femoral and tibial components.

Postoperative HKAA alignment (180° ± 3°)	Femoral and tibial component alignment (90° ± 2°)			
	Both inliers	Outliers (component malalignment)		
		Only femoral	Only tibial	Both
Inliers (n = 230, 57.21 %)	146 (63.48 %)	84 (36.52%)		
		39 (16.96 %)	30 (13.04 %)	15 (6.52 %)
Outliers (n = 172, 42.79 %)	21 (12.21 %)	151 (87.79%)		
		58 (33.72 %)	58 (33.72 %)	35 (20.35 %)

Table 3. Univariate logistic regression analysis.

Variables	The entire sample		Excluding HKAA outside the range of 180° ± 6°	
	OR (95 % CI)	p-value	OR (95 % CI)	p-value
Sex (male: Ref.)				
Female	1.50 (0.87,2.58)	0.141	1.57 (0.86,2.88)	0.142
ASA (yes: Ref.)				
No	1.38 (0.90,2.10)	0.135	1.51 (0.94,2.41)	0.085
Side (staged bilateral: Ref.)				
Unilateral	1.39 (0.86,2.25)	0.184	1.28 (0.76,2.16)	0.357
Diagnosis (OA: Ref.)				
RA	0.48 (0.15,1.52)	0.212	0.16 (0.02,1.25)	0.080
Hemophilia	1.31 (0.32,5.32)	0.705	1.31 (0.29,5.95)	0.726
Tibial defect (< 5mm: Ref.)				
> 5mm	1.58 (0.93,2.68)	0.088	1.59 (0.90,2.82)	0.110
Prothesis type (Triathalon: Ref.)				
Nexgen	1.49 (0.92,2.40)	0.105	1.21 (0.72,2.02)	0.477
Persona	0.63 (0.28,1.42)	0.265	0.37 (0.13,1.04)	0.060
Scorpio	0.72 (0.39,1.34)	0.302	0.58 (0.29,1.16)	0.125
Sigma	0.79 (0.36,1.73)	0.553	0.78 (0.34,1.79)	0.554
Femoral bowing (≤ 4.9°: Ref.)				
>4.9°	1.89 (1.25,2.85)	0.003	1.82 (1.16,2.86)	0.009
Tibial bowing (≤2.2°: Ref.)				
>2.2°	2.12 (1.40,3.21)	< 0.001	1.79 (1.14,2.81)	0.011
FC (≤10°: Ref.)				
>10°	2.94 (1.89,4.57)	< 0.001	1.99 (1.22,3.25)	0.006

Table 3. Continued

Preoperative HKAA (valgus knee: Ref.)				
0°-9° varus	1.66 (0.49,5.66)	0.420	1.63 (0.41,6.46)	0.488
10°-19° varus	2.91 (0.94,9.05)	0.064	2.96 (0.83,10.56)	0.094
≥ 20° varus	4.29 (1.32,13.92)	0.015	3.93 (1.05,14.72)	0.042
CCD angle (> 131°: Ref.)				
≤ 131°	1.57 (1.03,2.41)	0.038	1.42 (0.90,2.27)	0.135
Age (> 70 yrs: Ref.)				
≤ 70 yrs	1.48 (0.96,2.28)	0.079	1.49 (0.92,2.41)	0.104
BMI (> 30 kg/m²: Ref.)				
≤30 kg/m²	1.28 (0.86,1.91)	0.223	1.53 (0.98,2.39)	0.059
Preoperative JLCA (≤4°: Ref.)				
4°-10°	2.63 (1.31,5.28)	0.007	2.91 (1.29,6.56)	0.010
>10°	2.12 (0.99,4.56)	0.054	2.41 (1.00,5.81)	0.051
Preoperative MPTA (> 85°: Ref.)				
≤ 85°	2.18 (1.45,3.28)	< 0.001	2.17 (1.38,3.40)	0.001
Preoperative LDFA (≤ 91°: Ref.)				
> 91°	1.31 (0.88,1.94)	0.186	1.25 (0.81,1.93)	0.317
Varus type (4: Ref.)				
1	0.59 (0.33,1.05)	0.072	0.61 (0.32,1.15)	0.127
2	0.59 (0.35,1.02)	0.058	0.65 (0.36,1.17)	0.147
3	0.47 (0.14,1.51)	0.203	0.67 (0.20,2.20)	0.506

Seven variables significantly influenced the response variable when analyzing the entire sample [Table 3]. The most substantial effect was observed for FC, as the likelihood of experiencing an outlier postoperative HKAA in a knee with FC >10° was 2.94 times greater than a knee with FC ≤10° ($P<0.001$). The second most significant effect was attributed to the preoperative HKAA; individuals with a preoperative HKAA ≥20° varus had a 2.58 times higher chance of having an outlier postoperative HKAA compared to those with HKAA ≤9° varus ($P < 0.005$). The remaining variables that significantly affected postoperative HKAA, listed in order of effect size, included preoperative JLCA, preoperative MPTA, tibial bowing, femoral bowing, and the CCD angle. The findings remained consistent even when excluding postoperative HKAAs outside the 180° ± 6° range.

The seven significant variables identified in the univariate analyses were incorporated into the multivariate logistic model for both the entire sample and the excluded version of data [Table 4]. The findings were largely consistent, with the exception for preoperative HKAA, which showed no significant relationship when adjusted for other covariates in the multiple regression analysis. The most substantial effect observed in the whole sample analysis was again associated with FC. Thus, the likelihood of having an outlier for postoperative HKAA in a knee with FC > 10° was 2.95 times greater than in a knee with FC ≤ 10° ($P < 0.001$).

Table 4. Multivariate logistic regression analysis.

variables	The entire sample		Excluding the out of 6	
	OR (95 % CI)	*p-value*	*OR (95 % CI)*	*p-value*
Femoral bowing (≤ 4.9°: Ref.)				
> 4.9°	1.89 (1.21,2.98)	0.006	1.82 (1.13,2.94)	0.015
Tibial bowing (≤ 2.2°: Ref.)				
> 2.2°	2.00 (1.28,3.13)	0.002	1.82 (1.13,2.93)	0.013
FC (≤10°: Ref.)				
> 10°	2.95 (1.80,4.84)	<0.001	2.05 (1.19,3.54)	0.010
Preoperative HKAA (valgus knee: Ref.)				

Table 4. Continued

0°-9° varus	2.58 (0.67,9.88)	0.167	1.98 (0.46,8.56)	0.361
10°-19° varus	2.38 (0.66,8.53)	0.184	2.10 (0.52,8.46)	0.298
≥ 20° varus	3.17 (0.77,13.02)	0.110	2.37 (0.51,11.06)	0.271
CCD angle (> 131°: Ref.)				
≤ 131°	1.62 (1.01,2.59)	0.044	1.42 (0.86,2.34)	0.166
Preoperative JLCA (≤ 4°: Ref.)				
4°-10°	2.49 (1.13,5.48)	0.023	2.76 (1.13,6.77)	0.026
> 10°	1.30 (0.49,3.45)	0.603	1.75 (0.59,5.21)	0.313
Preoperative MPTA (> 85°: Ref.)				
≤ 85°	1.68 (1.03,2.73)	0.037	1.76 (1.05,2.96)	0.032

Finally, the risk of postoperative CM was calculated using the six variables that demonstrated significant effects in the multivariate logistic model for the entire sample [Table 5]. For instance, as indicated in the fifth row of this table, a patient undergoing conventional TKA with a femoral bowing > 4.9°, tibial bowing > 2.2°, and a CCD angle ≤ 131° would have a minimum risk of 50% for developing postoperative CM.

We also calculated the risk of postoperative CM based on the number of risk factors specifically the six significant variables identified in the multivariate model [Table 6]. The Chi-squared test revealed a significant difference in the risks of postoperative CM associated with varying numbers of risk factors ($P < 0.001$). In this analysis, 99 cases with a preoperative JLCA > 10° were excluded ($P = 0.603$).

Table 5. The probabilities of CM for significant variables in the multivariate regression model.

FC > 10°	*Preoperative JLCA (4°-10°)*	*Tibial bowing > 2.2°*	*Femoral bowing > 4.9°*	*Preoperative MPTA ≤ 85°*	*CCD angle ≤ 131°*	*Probability (%)*
NO	NO	NO	NO	NO	NO	0
NO	NO	NO	YES	YES	NO	33.3
NO	NO	YES	NO	YES	YES	33.3
NO	NO	YES	NO	NO	YES	14.3
NO	NO	YES	YES	NO	YES	50
NO	YES	NO	NO	YES	NO	16.7
NO	YES	NO	YES	YES	YES	63.6
NO	YES	NO	YES	YES	NO	40
NO	YES	NO	YES	NO	NO	16.7
NO	YES	YES	NO	YES	NO	55.6
NO	YES	YES	NO	NO	YES	35.7
NO	YES	YES	NO	NO	NO	14.3
NO	YES	YES	YES	NO	NO	58.3
YES	NO	YES	NO	YES	YES	50
YES	YES	NO	NO	YES	NO	33.3
YES	YES	YES	NO	YES	YES	71.4
YES	YES	YES	NO	NO	NO	50
YES	YES	YES	YES	YES	YES	100

Table 6. The risk of postoperative coronal malalignment (HKAA outside the range of 180° ± 3°) based on the number of risk factors present.

Number of risk factors	Normal alignment (inliers)	Coronal malalignment (outliers)	Chi-squared test
0	3 (100 %)	0 (0 %)	$P < 0.001$
1	11 (84.6 %)	2 (15.4 %)	$P < 0.001$
2	61 (81.3 %)	14 (18.7 %)	$P < 0.001$

Table 6. Continued			
3	50 (59.5 %)	34 (40.5 %)	P < 0.001
4	34 (44.7 %)	42 (55.3 %)	P < 0.001
5	13 (29.6 %)	31 (70.5 %)	P < 0.001
6	0 (0 %)	8 (100 %)	P < 0.001
Total	**N = 172**	**N = 131**	

Discussion

Achieving a neutral limb mechanical axis following TKA remains a notable challenge for knee surgeons.[5] It has been demonstrated that this alignment to substantially affect surgery outcomes.[18,22,23] To our knowledge, only two studies have specifically investigated the predictors of post-TKA CM, both of which focused on the computer-navigated techniques.[14,15] However, despite advancements in navigated and robotics-assisted TKA systems, conventional TKA, while less complex, continues to be the predominant method employed by orthopedic surgeons.[24,25] Moreover, although navigated TKA exhibits a lower outlier rate for coronal limb and component alignment [14,26,27], no significant differences have been observed in the long-term functional outcomes between navigated and conventional TKA.[27] There exists a knowledge gap regarding the factors resulting in postoperative CM in conventional TKA.[22,28] Therefore, we designed this study to identify the pre- and intraoperative risk factors associated with postoperative CM in conventional TKA. The most valuable findings of our study are as follows: the incidence of postoperative CM was 42.79%. According to multivariate logistic regression model analysis, the following factors were statistically associated with a greater chance of postoperative CM: FC > 10° (OR = 2.95, P < 0.001), femoral bowing > 4.9° (OR = 1.89, P = 0.006), tibial bowing > 2.2° (OR = 2.00, P = 0.002), preoperative MPTA ≤ 85° (OR = 1.68, P = 0.037), preoperative JLCA within 4° to 10° (OR = 2.49, P = 0.023), and a CCD angle ≤ 131° (OR = 1.62, P = 0.044) [Table 4].

In our study, the incidence of CM was 42.79%. A meta-analysis comparing postoperative mechanical axis malalignment between navigated and conventional TKAs reported a coronal alignment outlier rate of 31.2% in 1,376 conventional TKAs.[10] In another meta-analysis, the outlier rate for conventional TKA was reported to be 30% (range: 7% [29] to 54% [30]).[26] The significant variation in outlier rates may be due to the smaller sample sizes in most studies and the surgeon's experience, which plays a crucial role in the surgical outcomes.[15] We believe that the higher rate of postoperative CM observed in our study could be due to a subset of patients who achieved satisfactory outcomes but did not return for follow-up or were unable to complete the 3JRs assessments and thus were not included in the study.

We found that knee FC was the strongest predictor of postoperative CM (OR = 2.95, 95% confidence interval [CI]: 1.80-4.84). Similarly, Chowdhry et al. found FC as the second strongest predictor of CM in navigated TKAs, which increased the likelihood of being classified as an outlier by 29%.[14] Interestingly, our study showed that FC had an even more detrimental effect on postoperative CM in patients with postoperative HKAA deviation greater than ±6° (OR = 7.14, 95% CI: 3.38-15.08) [Table 7]. We conclude that the effective management of FC during TKA may help prevent more severe degrees of postoperative CM.

Table 7. The univariate and multivariate logistic models considering postoperative HKAA > ± 6° as indicators of coronal limb alignment outliers.

Variables	Univariate model		Multivariate model	
	OR (95 % CI)	**p-value**	**OR (95 % CI)**	**p-value**
Femoral bowing (≤ 4.9°: Ref.)				
> 4.9°	1.66 (0.89,3.11)	0.110	1.78 (0.89,3.55)	0.102
Tibial bowing (≤ 2.2°: Ref.)				
> 2.2°	3.00 (1.40,6.41)	0.005	2.50 (1.12,5.56)	0.025
FC (≤ 10°: Ref.)				
> 10°	6.57 (3.35,12.9)	< 0.001	7.14 (3.38,15.08)	< 0.001
Preoperative HKAA (< 0°: Ref.)				
0°-9°	1.58 (0.17,14.41)	0.686	4.14 (0.40,43.27)	0.235
10°-19°	2.09 (0.27,16.33)	0.483	2.61 (0.28,24.18)	0.398
≥ 20°	3.60 (0.45,29.06)	0.229	4.47 (0.41,48.48)	0.218
CCD angle (> 131°: Ref.)				
≤ 131°	1.89 (0.90,3.94)	0.091	1.84 (0.83,4.10)	0.135

Table 7. Continued				
Preoperative JLCA (≤ 4°: Ref.)				
4°-10°	1.52 (0.51,4.53)	0.450	1.35 (0.38,4.75)	0.643
> 10°	1.24 (0.37,4.16)	0.732	0.52 (0.11,2.48)	0.412
Preoperative MPTA (> 85°: Ref.)				
≤ 85°	1.70 (0.88,3.27)	0.112	1.07 (0.49,2.35)	0.857

The relationship between femoral bowing and postoperative CM has been addressed only in limited number of studies. Our findings indicate that femoral bowing greater than 4.9° may serve as a predictor of postoperative CM. A radiological study involving 360 patients who underwent conventional TKA showed that preoperative femoral bowing > 5° results in inaccuracies in femoral component positioning, subsequently leading to CM, which is consistent with our findings.[31] Similarly, Mullaji et al. revealed that femoral bowing > 5° was associated with postoperative CM in navigated TKA.[15]

Yau et al. demonstrated that, in addition to preoperative varus deformity, preoperative tibial bowing also contributes to postoperative CM.[19] Similarly, we found that tibial bowing was one of the strongest predictors of postoperative CM, with an OR of 2.00 (95% CI: 1.28-3.13) for all TKAs and 3.00 (95% CI: 1.40-6.41) for cases with a HKAA deviation greater than ± 6° [Table 7].

In the univariate model, we found that a preoperative varus angle of ≥ 20° was significantly associated with postoperative CM. However, the multivariate model did not show such an association. In contrast to our findings, Mullaji et al. found a notable association between varus deformity greater than 20° and postoperative CM in a study involving 1,500 navigated TKAs.[15] We believe that this discrepancy may stem from differing levels of statistical adjustment between the two studies. Thus, we excluded the MPTA from the multiple regression analysis and interestingly observed that a varus angle of ≥ 20° significantly enhanced the risk of postoperative CM (OR = 5.07, P = 0.017), even stronger than FC [Table 8]. Therefore, we conclude that MPTA is a more reliable predictor of postoperative CM. Additionally, a preoperative JLCA of 4°-10° appeared to be significantly associated with postoperative CM (OR = 2.49, P = 0.023). This factor has not been studied in relative previous researches.

Table 8. The multivariate logistic regression model after excluding the MPTA from the analysis.

Variables	The entire sample	
	OR (95 % CI)	p-value
Femoral bowing (≤ 4.9: Ref.)		
> 4.9	1.90 (1.21,2.98)	0.005
Tibial bowing (≤ 2.2: Ref.)		
> 2.2	2.00 (1.31,3.20)	0.002
FC (≤ 10: Ref.)		
> 10	2.95 (1.83,4.91)	< 0.001
Preoperative HKAA (valgus knee: Ref.)		
0°-9° varus	2.78 (0.74,10.54)	0.132
10°-19° varus	3.23 (0.94,11.13)	0.063
≥ 20° varus	5.07 (1.33,19.33)	0.017
CCD angle (> 131°: Ref.)		
≤ 131°	1.61 (1.07,2.57)	0.047
Preoperative JLCA (≤ 4°: Ref.)		
4°-10°	2.24 (1.03,4.87)	0.042
> 10°	1.05 (0.41,2.72)	0.92

Since hip geometry, assessed by the CCD angle in our study, is a crucial determinant of the lower limb mechanical axis, we evaluated the association between the CCD angle and postoperative CM. To the best of our knowledge, this relationship has not been explored in related studies so far. Our findings indicate that patients with a CCD angle less than 131° are at a 69% higher risk of experiencing postoperative CM compared to those with a CCD angle greater than 131°. In other words, patients with coxa vara are more susceptible to postoperative CM than those with coxa valga.

Our study had several limitations. First and foremost, the radiographic evaluation was prone to measurement errors, primarily due to discrepancies in limb positioning.[32] Despite our efforts to minimize this error by standardizing the technique for obtaining 3JRs, we believe there was a notable possibility that some of our results were influenced by subtle changes in limb rotation. Secondly, the alignment of the lower limb and its components in the sagittal and axial planes was not considered in this study, as the focus was primarily on coronal plane alignment, similar to previous studies. However, it is important to note that sagittal and axial alignments are critical for the long-term implant survival of implants.[33,34] Furthermore, the retrospective design of our study introduces the potential for selection bias, underscoring the necessity for prospective studies to confirm our findings. Finally, the use of an extramedullary guide for the proximal tibial cut may have contributed to tibial malalignment. To minimize this issue, we carefully aligned the guide with the tibial mechanical axis and performed intraoperative checks, although this remains an inherent limitation of the technique.

Our study also had several strengths. First, to the best of our knowledge, it is the first population-based retrospective cohort study that aimed at identifying the pre- and intraoperative clinical and radiological predictors of postoperative CM in conventional TKA. Secondly, all operations were performed by a single high-volume arthroplasty surgeon using a consistent technique, which significantly reduced registration errors and performance bias. Finally, the association between the predictors and postoperative CM remained constant even after excluding cases with extreme postoperative HKAAs greater than ±6°. This finding underscores the powerful association between these factors and postoperative CM.

Conclusion

Our findings indicate that a FC >10°, femoral bowing >4.9°, tibial bowing >2.2°, a CCD angle ≤131°, a JLCA 4°-10°, and a MPTA ≤85° (or a HKAA ≥20°) are significant risk factors for postoperative CM in patients undergoing primary conventional TKA using a mechanical strategy. The risk of postoperative CM can be estimated based on these factors. For instance, we found a postoperative CM risk of 40.5% for patients having ≥3 of these risk factors. A higher risk may prompt the surgeon to address these factors and perform TKA with greater precision. It may be prudent to reserve advanced techniques, such as patient-specific instrumentation and computer-assisted navigation, for those patients identified as having a high risk of post-TKA CM. However, this should be confirmed in future studies.

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Sadegh Hasani Satehi MD [1]
Mohammadreza Razzaghof MD, MPH [1, 2]
Amirhossein Rahimnia MD [3]
Seyed Saeed Tamehri Zadeh MD [3]
Milad Salehi MD [1]
SM Javad Mortazavi MD [1, 2]

1 Joint Reconstruction Research Center (JRRC), Tehran University of Medical Sciences, Tehran, Iran

2 Department of Orthopedic Surgery, Imam Khomeini Hospital Complex, Tehran University of Medical Sciences, Tehran, Iran

3 Department of Medicine, Tehran University of Medical Sciences, Tehran, Iran

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