RESEARCH ARTICLE

Predicting Femoral Component Rotation in Mechanically Aligned Total Knee Arthroplasty: Can Preoperative Three-Joint Alignment Radiograph Help?

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Abstract

Objectives: Achieving precise femoral component external rotation (FCER) is crucial in Total Knee Arthroplasty (TKA) to prevent patellofemoral maltracking, implant loosening, pain, and wear. While CT scans and MRIs help determine the rotational profile of the distal femur, their use is limited by concerns about radiation exposure and cost. This study aims to explore the potential role of a preoperative three-joint alignment radiograph in predicting the necessary FCER for mechanically aligned TKA.

Methods: This retrospective cohort study was conducted on 922 patients (1,208 knees) with varus deformity who underwent primary TKA performed by a single knee surgeon between 2018 and 2020. The angular parameters from the three-joint alignment radiograph and FCER were extracted from the JRRC Knee Registry. These angular parameters included the lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), joint line congruency angle (JLCA), and varus angle (VA). FCER was determined intraoperatively based on standard anatomical criteria, including Whiteside's line, the trans-epicondylar line, posterior condylar axis, anteroposterior axis, and the assessment of the proximal tibial cut. Data analysis was performed using SPSS 26.

Results: A total of 922 patients (57.9% female, 42.1% male) with a mean age of 65.39 ± 8.03 years (range: 43-90) were included in the study. The FCER was 0° in 0.33%, 3° in 83.6%, 5° in 15.23%, and 7° in 0.82% of patients. FCER showed no correlation with MPTA, LDFA, or VA, but it was significantly correlated with JLCA/LDFA, JLCA/MPTA, and JLCA/VA, with cut-offs at 0.11, 0.12, and 0.62, respectively. JLCA/MPTA emerged as the best predictor for FCER in TKA (sensitivity = 48%, specificity = 81%, and accuracy = 0.67).

Conclusion: Preoperative three-joint alignment radiographs can guide the surgeon in determining the required FCER during TKA. If the ratios exceed the established cut-offs, an FCER greater than 3° may be necessary.

Level of evidence: III

Keywords: Alignment view, Femoral component external rotation, Mechanical strategy, Total knee arthroplasty

Introduction

The rotational alignment of the femoral component is crucial for achieving favorable long-term outcomes in total knee arthroplasty (TKA).[1] Improper rotational alignment can lead to patellofemoral complications, including patellar subluxation/dislocation, tilting, maltracking, implant loosening, painful TKA, flexion gap imbalance, and increased wear.[2-6]

TKA can be performed using different strategies. The mechanical strategy aims to achieve a 90° angle in the lateral distal femoral angle (LDFA) and medial proximal tibial angle (MPTA), while ensuring that the joint line remains parallel. Since the medial condyle of the distal femur is larger posteriorly, it is positioned in a state of internal rotation.[7,8,9] In this mechanical approach, the distal femoral cut is made with 3° of external rotation to ensure a balanced 94° flexion-extension gap. However, this external

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rotation may vary among patients and can be determined intraoperatively based on landmarks such as Whiteside's line (WSL), the trans-epicondylar axis (TEA), posterior condylar axis (PCA), anteroposterior axis (APA), and assessment of the proximal tibial cut.[10-12] Combining these factors can help determine the appropriate femoral component external rotation (FCER). Advanced imaging modalities, such as CT scans and MRI, have been used to determine the FCER when necessary.

However, the routine use of these imaging techniques in preoperative planning for TKA is generally discouraged, primarily due to concerns about radiation exposure and additional costs.[13-20] Therefore, predicting the required FCER solely based on preoperative radiographs can minimize patient exposure to radiation, reduce costs, and optimize surgical outcomes. To date, no study in the current literature has investigated the relationship between coronal angles in standing three-joint alignment radiographs and the degree of FCER.

Therefore, this study was conducted to evaluate the relationship between the three-joint alignment angular parameters and the FCER determined during surgery, with the aim of predicting the correct amount of FCER in patients undergoing TKA for osteoarthritic varus knees.

Materials and Methods

In this retrospective cohort study conducted at the Joint Reconstruction Research Center of Tehran Imam Khomeini Hospital Complex, 922 patients (1,208 knees) with varus knee deformity who underwent primary Total Knee Arthroplasty (TKA) between 2018 and 2020 were included. All surgeries were performed by an experienced knee surgeon using the NexGen PS Knee prosthesis (Zimmer Biomet). The study was approved by the Institutional Review Board of Tehran University of Medical Sciences (TUMS) and received ethical approval under code IR.TUMS.IKHC.REC.1401.188.

Patients with valgus knee deformity, those undergoing revision or conversion surgeries, and those with hemophilic arthropathy were excluded from the study. Data from the patients, including three-joint alignment radiograph parameters and femoral component external rotation (FCER) angles, were extracted from the Joint Reconstruction Research Center Knee Registry database.

The main variables included age, sex, weight, surgery side, mechanical anatomical angle (MAA), lateral distal femoral angle (LDFA), medial proximal tibial angle (MPTA), joint line congruency angle (JLCA), varus angle of the lower limb (VA), JLCA/LDFA, JLCA/MPTA, JLCA/VA, and FCER, all of which were extracted from the patients' files. The primary outcome of our study was the FCER angle, which was measured and double-checked during surgery using the standard anatomic parameters outlined below. We defined the FCER for each knee as the closest angle to the predefined external rotation angles of the femoral component, as specified by the manufacturer (Zimmer Biomet: 0°, 3°, 5°, and 7°).

Surgical technique

All patients underwent TKA using the same surgical technique in the supine position. The midline anterior approach was utilized, involving a skin incision and opening of the retinaculum through a medial parapatellar incision. Patellar tracking was assessed by flexing and extending the knee, followed by a final check and comparison after the components were installed.

The procedure began with a femoral cut using an intramedullary (IM) drill to access the femoral canal and apply a distal femoral IM jig. Subsequently, the component size was determined based on the anterior-posterior diameter of the femoral condyle to ensure proper fit. The Femoral Component External Rotation (FCER) was measured using criteria such as the posterior condylar axis (PCA), Whiteside's line (WSL), or the native trans-epicondylar axis (TEA) during surgery.

Next, the proximal tibia was cut using an intramedullary (IM) guide to align the cut perpendicular to the tibial axis. After the tibial cut, the extension and flexion gaps were evaluated. The rotation was reassessed after making cuts on the femur and tibia by examining the surface of the proximal tibial cut.

Once this step was completed, the femoral and tibial trial implants were carefully positioned, and a provisional spacer trial was inserted. After confirming the accuracy, the main cemented components for the femur, tibia, and polyethylene were inserted. Finally, the wound was sutured, and a sterile dressing was applied.

Statistical Analysis

Descriptive and inferential statistics were applied, tailored to the types of variables. The Jarque-Bera and Anscombe-Glynn tests were used to assess normality in quantitative variables. The unpaired independent t-test was used for normally distributed data, while the Mann-Whitney test was used for non-normally distributed data. The one-way ANOVA test was used for normally distributed data, and the Kruskal-Wallis test was applied for non-normally distributed data to compare quantitative variables among three or more groups. The chi-square and Fisher's exact tests were used to assess the relationship between qualitative variables. ROC curve analysis was performed to determine the optimal cut-off value of angular parameters for predicting FCER during TKA.

Statistical indices were reported as the mean ± standard deviation for normally distributed variables, the median (Interquartile Range) for non-normally distributed variables, and frequency percentages for categorical variables. Data analysis was performed using SPSS version 26, with a significance level of 5% considered.

Results

A total of 922 patients (1,208 knees) were included in the study. The mean ages of males and females were 69.29 and 64.76 years, respectively, indicating a statistically significant difference ($P < 0.001$). The demographic data of the patients are shown in [Table 1].

The FCER of our patients is illustrated in [Figure 1]. The covariance test results, adjusted for age, revealed that FCER was significantly higher in females than in males after accounting for age differences ($P < 0.001$) [Table 2].

Table 1. The demographic data of the patients		
		Mean ± SD (range) or Frequency (percent)
Age (years)		65.39 ± 8.03 (43- 90)
Weight (Kg)		76.88 ± 12.27 (34.0 -120)
Height (cm)		167.63 ± 6.46 (110- 183)
Sex	*Male*	388 (42.1 %)
	Female	534 (57.9 %)
Leg Side	*L*	630 (52.2 %)
	R	578 (47.8 %)

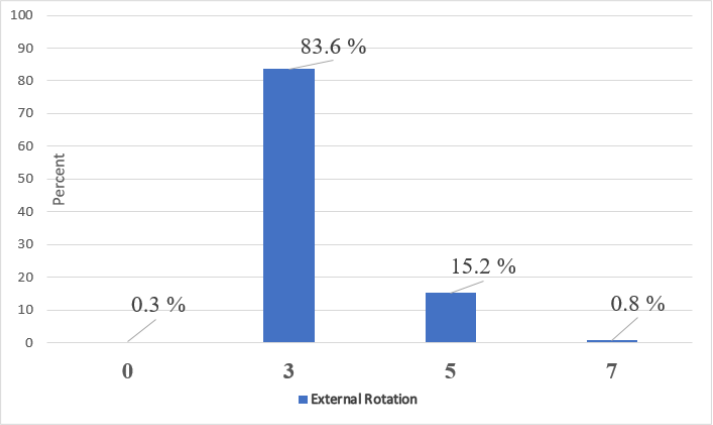

Figure 1. The frequency distribution results for external rotation in varus knee based on VA

Table 2. External rotation of femur by covariance test						
	Sex	**N**	**Mean**	**Std. Deviation**	**P-value***	**Adjusted P-value #**
External rotation	Male	388	3.06	0.340	< .001	< .001
	Female	534	3.37	0.860		

*Independent Samples T-test # Analysis of Covariance adjusted by Age

The correlation of external rotation with MAA, LDFA, JLCA/LDFA, MPTA, JLCA/MPTA, VA, and JLCA/VA was analyzed using Spearman's correlation test [Table 3]. The results showed that FCER significantly correlated with LDFA, JLCA/LDFA, MPTA, JLCA/MPTA, VA, and JLCA/VA. Specifically, as LDFA and MPTA increased, FCER decreased significantly, while JLCA/LDFA, JLCA/MPTA, and JLCA/VA decreased, and FCER increased significantly ($P < 0.05$).

Table 3. Correlation of external rotation with three-joint alignment radiograph parameters								
		MAA	**LDFA**	**JLCA/LDFA**	**MPTA**	**JLCA/MPTA**	**VA**	**JLCA/VA**
E.R	Correlation Coefficient	0.034	-0.096	0.226**	-0.081**	0.217**	0.141**	0.084*
	P-Value	0.233	0.001	0.000	0.005	0.000	0.000	0.004
	N (knee)	1208						

E.R; External rotation

** Correlation is significant at the 0.01 level (P-value)

* Correlation is significant at the 0.05 level (P-value)

The mean JLCA/LDFA, JLCA/MPTA, and JLCA/VA were compared between different FCER angles [Table 4]. The results of the ANOVA test with repeated measures showed that the differences in the average JLCA/LDFA, JLCA/MPTA, and JLCA/VA between different FCER angles were statistically significant (P < 0.05). Subsequently, Tukey's post hoc test was used for pairwise comparisons, and the results are shown in [Tables 5-7]. Two criteria, JLCA/LDFA and JLCA/MPTA, significantly predicted FCER with acceptable sensitivity and specificity (Accuracy: 0.60 for JLCA/LDFA and 0.67 for JLCA/MPTA). The area under the curve (AUC) demonstrates the accuracy of these criteria [Figure 2, Table 8].

Table 4. The comparison of JLCA/LDFA, JLCA/MPTA, and JLCA/VA between different external rotation angles

E.R		JLCA/LDFA	JLCA/MPTA	JLCA/VA
0	N (Mean± SD)	4 (0.12 ± 0.04)	4 (0.13 ± 0.05)	4 (0.58 ± 0.20)
3	N (Mean± SD)	1010 (0.093 ±0.05)	1010 (0.098 ± 0.04)	1010 (0.66 ±0.45)
5	N (Mean± SD)	184 (0.12 ± 0.06)	184 (0.13 ± 0.06)	184 (0.77 ± 0.58)
7	N (Mean± SD)	10 (0.18 ± 0.08)	10 (0.22 ± 0.10)	10 (0.58 ± 0.28)
Total	N (Mean± SD)	1208 (0.09 ± 0.05)	1208 (0.10 ± 0.05)	1208 (0.68 ± 0.47)
	P-value	< 0.001	< 0.001	0.024

E.R; External rotation, N; Number, SD; Standard deviation

Table 5. Comparison of JLCA/LDFA in individuals with different external rotations analyzed by Tukey's post hoc test

Dependent Variable	(I) E.R	(J) E.R	Mean Difference (I-J)	P-value
JLCA/LDFA	0	*3*	0.02	0.74
		5	-0.00	10.00
		7	-0.06	0.19
	3	*0*	-0.02	0.74
		5	-0.03*	0.00
		7	-0.09*	0.00
	5	*0*	0.00	10.00
		3	0.03*	0.00
		7	-0.06*	0.00
	7	*0*	0.06	0.19
		3	0.09*	0.00
		5	0.06*	0.00

E.R; External rotation

Table 6. Comparison of JLCA/MPTA in individuals with different external rotations analyzed by Tukey's post hoc test

Dependent Variable	(I) E.R	(J) E.R	Mean Difference (I-J)	P-value
JLCA/MPTA	0	*3*	0.03	0.46
		5	0.00	10.0
		7	-0.08*	0.01
	3	*0*	-0.03	0.46
		5	-0.03*	0.00
		7	-0.12*	0.00
	5	*0*	0.00	10.00
		3	0.03*	0.00
		7	-0.08*	0.00
	7	*0*	0.08*	0.01
		3	0.12*	0.00
		5	0.08*	0.00

E.R; External rotation

Table 7. Comparison of JLCA/VA in individuals with different external rotations analyzed by Tukey's post hoc test

Dependent Variable	(I) E.R	(J) E.R	Mean Difference (I-J)	P-value
JLCA/VA	0	*3*	-0.07	0.98
		5	-0.18	0.86
		7	0.00	10.00
	3	*0*	0.07	0.98
		5	-0.11*	0.01
		7	0.08	0.94
	5	*0*	0.18	0.86
		3	0.11*	0.01
		7	0.19	0.58
	7	*0*	-0.00	10.00
		3	-0.08	0.94
		5	-0.19	0.58

E.R; External rotation

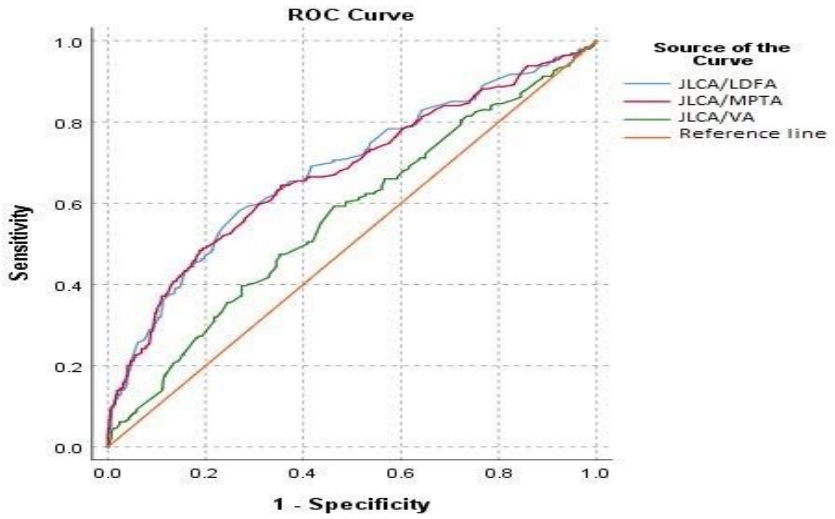

Figure 2. ROC curves of JLCA/LDFA, JLCA/MPTA, and JLCA/VA in predicting the external rotation of the femoral component

Table 8. The ROC analysis of JLCA/LDFA, JLCA/MPTA, and JLCA/VA in predicting the external rotation of the femoral component

	AUC	P-value	Cut off	Sensitivity	Specificity	Accuracy
JLCA/LDFA	0.68	0.000	0.11	0.58	0.72	0.602
JLCA/MPTA	0.67	0.000	0.12	0.48	0.81	0.677
JLCA/VA	0.56	0.004	0.62	0.59	0.53	0.443

Discussion

In this study, we explored the relationship between preoperative three-joint alignment radiographs and the necessary FCER during TKA performed using the mechanical strategy. We found that this rotation did not correlate with MAA, LDFA, MPTA, or VA; however, it did show significant correlations with JLCA/LDFA, JLCA/MPTA, and JLCA/VA. According to the results, JLCA/LDFA and JLCA/MPTA demonstrated sufficient sensitivity and specificity in predicting the degree of FCER (0.60 for JLCA/LDFA and 0.67 for JLCA/MPTA).[21] However, JLCA/MPTA appeared to be a better predictor than JLCA/LDFA and JLCA/VA, with a sensitivity of 48% and specificity of 81%. The cut-off values for JLCA/LDFA, JLCA/MPTA, and JLCA/VA were 0.11, 0.12, and 0.62, respectively. If these ratios exceed the established cut-offs, the surgeon should consider that the required FCER will likely be greater than 3°, i.e., 5° or 7°, with

corresponding sensitivities and specificities.

The occurrence of osteoarthritis is noticeably more common in women than in men worldwide, possibly due to variations in knee movement, weaker quadriceps, vitamin D deficiency, and estrogen deficiency in postmenopausal women.[22] Additionally, the ratio of women to men undergoing TKA surgery is higher.[23] In other studies [Table 1], this may be because Iranian women are more attentive to their health and more open to undergoing surgery. In contrast, men are generally less willing to undergo TKA, as they tend to work until an older age and are less accepting of the post-TKA limitations.[24,25]

Jabal Ameli et al.[15] assessed the rotational alignment of the distal femur and found that women exhibited greater external rotation than men. Our study also yielded similar results, and this difference was statistically significant, suggesting that a gender difference may exist in the rotational alignment of the distal femur.

Previous studies[14-20] have primarily used advanced imaging modalities, such as CT scans and MRI, to evaluate the rotational profile of the distal femur. However, these techniques have notable disadvantages, including elevated patient costs and the risk of harmful radiation exposure associated with CT scans. In contrast, our study utilized three-joint alignment radiographs, which are already part of the preoperative workup for every TKA.[26,27] This approach minimizes radiation exposure to patients and incurs no additional cost.

The evaluation of FCER using radiography has only been studied by Kanekasu et al.[27] They employed axial view radiography to compare the prominence of the epicondyle and the clinical epicondylar axis with the clinical criterion of the posterior condylar axis (PCA) in determining FCER. Their study found a constant external rotation of 3 degrees and no significant differences among individuals. The limitation of axial radiography lies in its reproducibility when detecting anatomical landmarks. Identifying the medial sulcus to determine the clinical epicondylar axis can be challenging. If this identification is not performed accurately, the landmarks may not be recognizable on the axial view radiography, leading to potential errors in surgical planning. In contrast, our findings indicated that the degree of FCER in varus knees, as determined by mechanical principles, varied among patients, likely due to the anatomical characteristics of the distal femoral bone. Our study revealed that 16% of the knees had an external rotation of more than 3 degrees.

To minimize errors in mechanical alignment, we used both internal and external modular guides for distal femoral and proximal tibial cuts. Similarly, to reduce errors in FCER measurement, all parameters, including the grand piano sign,[26] trans-epicondylar axis (TEA), Whiteside's line (WSL), and posterior condylar axis (PCA) were used and verified with a proximal tibial cut.[11,12,28] Additionally, the surgeon double-checked the FCER during the procedure.

One of the major strengths of this study was its relatively large sample size compared to similar previous studies. Secondly, unlike earlier studies, our study did not use CT scans or MRI to determine the external rotation of the distal femur. Instead, we utilized the routine preoperative three-joint alignment radiograph, thereby avoiding additional costs and radiation exposure for the patients. Thirdly, all procedures were performed by the same surgeon using a consistent prosthesis type.

Regarding the limitations, a precise assessment of FCER typically requires a CT scan or MRI. However, our study relied exclusively on surgical landmarks such as the trans-epicondylar axis (TEA), clinical epicondylar axis (CEA), posterior condylar axis (PCA), the grand piano sign, and flexion-extension gap balance, which may not be measured with complete accuracy. Ethical considerations prevent the routine use of CT scans and MRIs due to their additional cost and radiation burden on patients. Furthermore, this study was conducted at a single center, which may introduce bias when compared to the general population. The performance and analysis of three-joint alignment radiographs are dependent on the operator. This error can be minimized by performing the radiographs at the same imaging center with a consistent operator. Additionally, patient follow-up was not part of our study, with only post-surgery outcomes being reported. Therefore, it is essential to note that while the findings of this study are intriguing, further replication and validation in larger, multi-center studies are recommended.

Conclusion

This study demonstrated that the preoperative three-joint alignment radiograph can guide the surgeon in determining the required degree of FCER during TKA. The ratios of JLCA/LDFA, JLCA/MPTA, and JLCA/VA provide a straightforward method for predicting FCER, with respective cut-off values of 0.11, 0.12, and 0.66. If these ratios exceed their established cut-offs, the surgeon will be alerted that FCER may exceed the standard 3°. Based on preoperative planning, the FCER will be set to 5 or 7 degrees in these cases. These calculated degrees are then verified using surgical landmarks to ensure their accuracy and prevent potential complications from malrotation.

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