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Rotational Analysis of Femur and Tibia with Bilateral Lower Extremity Computed Tomography Measurements: A Retrospective Study

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ABSTRACT

Introduction: This study aimed to emphasize the importance of assessing and correcting rotational alignment of the lower extremities after trauma. To examine the effects of differences in femoral and tibial rotation on optimal patient outcomes.

Methods: This single-center retrospective study was conducted at University of Health Sciences Turkey, İstanbul Training and Research Hospital in accordance with the guidelines of the Declaration of Helsinki. The study involved 130 patients who underwent lower extremity computed tomography (CT) angiography or venography between May 2015 and December 2022. Patients underwent CT scan in the supine position with their legs extended. Radiographic parameters were measured digitally, and femoral and tibial rotation angles were calculated.

Results: The mean femoral and tibial rotations were 12.2° and 31.3°, respectively. No significant difference was observed between femoral and tibial rotations in terms of sex. There was a moderate correlation in femoral rotation and a high correlation in tibial rotation between the right and left sides.

Conclusion: Gender was not a significant factor in the assessment of lower extremity rotational alignment. The importance of considering bilateral differences during surgical procedures is emphasized. These findings may help clinicians make more informed decisions when assessing and treating patients. However, further research is required before these findings are fully integrated into clinical practice.

Keywords: Femoral rotation, tibial rotation, rotational alignment, surgical planning

Introduction

Assessment and correction of rotational alignment in the lower extremities, especially after trauma, are crucial for optimal patient outcomes. There can be significant differences between femoral and tibial rotation in healthy individuals, and precise assessment methods may be required for patients with axial plane deformities. The healthy side often refers to the pre-traumatic rotation of the affected bones, particularly in comminuted fractures where anatomical landmarks are lost. Rotational dislocation is an important clinical problem after closed nailing of femoral and tibial shaft fractures, with rotational differences exceeding 15**°** in the femur and 10**°** in the tibia considered true deformities that may require corrective osteotomy (1).

Various methods have been proposed to accurately assess tibial rotation. For example, the intermalleolar method has demonstrated high accuracy by providing intraoperative tibial rotational measurements within 10 degrees of CT measurements, making it a reliable tool for intraoperative corrections (2). Furthermore, fibular alignment has been suggested as a surrogate marker for tibial rotation. Significant malrotation is probably absent when fibular contact disappears during medullary nailing (3).

The C-arm method using lateral axis views has also shown high accuracy in predicting CT measurements and preventing postoperative malrotation, with no reported incidence of malrotation greater than 10° (4). Furthermore, the thigh-foot angle and transmalleolar axis are common methods to assess tibial torsion, but their validity may be limited by foot alignment. Overall, CT-based torsion angle calculations remain a reliable indicator of malrotation, with studies showing a higher incidence of misalignment than previously reported, with studies underscoring the importance of accurate rotational assessment and correction in clinical practice (1).

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This study aimed to examine the importance of assessment and correction of lower extremity rotational alignment after trauma for optimal patient outcomes. It is known that differences between femoral and tibial rotations can play an important role in the correct diagnosis and treatment of patients with axial plane deformities. In this context, our research aimed to examine the accuracy and reliability of assessment methods used in both healthy individuals and patients with rotational deformities and to determine reference values that can be used in surgical planning and intraoperative correction.

Methods

This single-center retrospective study was conducted at University of Health Sciences Turkey, İstanbul Training and Research Hospital according to the guidelines of the Declaration of Helsinki. The University of Health Sciences Turkey, İstanbul Training and Research Hospital Ethics Committee approved the study (approval number: 76, date: 09.08.2024). Informed consent was obtained through an "opt-out" form available on the hospital website. The sample size of the study is 130 patients included; 113 were male and 17 were female. All patients who underwent lower extremity CT angiography or venography at our hospital between May 2015 and December 2022 were identified using the hospital's Picture Archiving and Communication System (PACS). Patients with complete lower extremity CT angiography or venography images showing the entire femur, tibia, and talus on both sides were included. Patients under the age of 20 or over the age of 60 with leg asymmetry or flexion, osteoarthritis (OA) of the hip and knee joints with joint deformity (Kellgren and Lawrence grade 2/3/4) (5), endoprosthesis of the hip, knee, or ankle joint, postoperative variations in the lower extremity, or posttraumatic changes in the lower extremity were excluded.

Data Collection

The rotational alignment analysis was performed using lower extremity computed tomography (CT) angiography or venography. Patients were placed in the supine position stabilized with belts with their legs extended, while their ankles and knees were in contact with the table and each other. The ankles were 90° flexed with 45° between their toes during a standardized CT examination protocol. CT scans were performed using a 64-slice CT system (Toshiba, Aquilion, Tokyo, Japan) and a 128-slice CT system (Philips Brilliance 128, Amsterdam, Netherlands) with predetermined reconstruction parameters. 0.4 mm thick slices, 120 Kvp, and 80 mass were reconstructed from raw data.

Radiographic parameters were measured in the axial direction. Digital measurements were performed using the RİS-PACS image archiving system (Simple PACS V2, İzmir, Turkey). The measurements were performed independently by three orthopedic surgeons who were familiar with rotation analyses. The rotation angle values were calculated by averaging the two observers' measurements.

Femoral rotation was defined as the angle formed by the femoral neck and the line intersecting the distal femur's posterior condylar line (PCL). Reikerås et al. (6) defined the femoral neck axis as the line between the center of the femoral head and the middle of the neck in two CT sections with the widest femoral head and neck.

Positive and negative values indicated femoral retroversion and femoral neck anteversion, respectively, concerning the PCL. Tibial rotation was measured as the angle formed by the line connecting the posterior parts of the proximal tibial condyles to the bimalleolar axis. The line linking the posterior parts of the proximal tibial condyle was expanded to the top of the fibula (7).

In a cross-section just below the articular surface of the tibial pylon, the bimalleolar axis runs between the malleoli and the center of the talus dome (8). Positive values represent external rotation of the tibia. Negative values indicate internal rotation of the distal tibia with respect to the proximal posterior tibial plateau.

Furthermore, the knee and total leg rotation alignments were evaluated. Knee rotation was calculated as the angle created by the line linking the posterior proximal tibial condyles and distal femoral PCL. Positive values were used to represent the external rotation of the knee. These variables provide evidence of knee laxity in the extension position. Leg rotation with the knee was defined as the total axial lower-limb rotation based on the angle formed by the femoral neck and bimalleolar axes, which includes potential rotational elements caused by knee laxity. Leg rotation without the knee was defined as the total axial lower-limb rotation angle after subtracting the knee rotation, excluding potential rotational elements due to knee laxity.

Statistical Analysis

The SAS 9.4 package was used for the statistical analysis of the data obtained in this study. For the quantitative variables of the study determined by measurement, descriptive statistics were presented as mean and standard deviation; for the qualitative variables determined by counting, descriptive statistics were presented as numbers and percentages. The variables used in this study were first tested for conformity to a normal distribution using the Shapiro-Wilk test. For this purpose, Skewness values were also analyzed.

As a result of the tests, all variables were found to be normally distributed, and parametric tests were used in the statistical analysis. The paired two-sample t-test was used to compare the mean differences between right and left rotations. Student's two-sample t-test was used to compare rotation and individual bilateral differences (IBD) by gender. Pearson's correlation coefficient was calculated for the correlation of right-left rotations. The significance level was set at 0.05 throughout the study.

Results

In this study, a total of 130 consecutive bilateral lower extremity CT angiography and venography images of the femur and tibia were analyzed. The general descriptive statistics and gender comparison results obtained from the analysis are presented in Table 1. The study included 130 patients, with a mean age of 55.9±15.06 years, 55.8±15.15 years for males and 56.4±14.90 years for women.

Pearson's correlation coefficients between the right and left lower extremities for all patients are presented in Table 2. The Pearson correlation coefficient of femoral rotation between the right and left sides showed a positive, moderate, and statistically significant relationship for all patients (r=0.59, p=0.0001). In contrast, the Pearson correlation coefficient of tibial rotation between the right and left sides was positive, high, and statistically significant (r=0.76, p=0.0001).

A comparison of the measurements of the right and left lower extremities among all patients is presented in Table 3. In the analysis of all extremities, the mean absolute bilateral difference (ABD) of femoral rotation was 5.11°, and the mean ABD of tibial rotation was 5.19°. Similarly, the mean relative bilateral difference (RBD) of femoral rotation was 0.57°, and the RBD of tibial rotation was 2.28° for all extremities. The RBD of femoral rotation showed no statistically significant difference between the right and left sides. The RBD of tibial rotation revealed a statistically significant difference between the right and left sides (p=0.0004), with the right side having a significantly higher external rotation.

Table 4 compares the results of measuring the right and left lower extremities according to gender. There was a significant difference between the right and left lower extremity averages of femoral rotation in males. A statistically significant difference was found between the right and left lower extremity averages of femoral rotation in females (p=0.0001) and a significantly higher internal rotation was observed on the left side. Moreover, when the comparisons of the measurements of the right and left lower extremities of the tibial rotations of different genders are examined, it is seen that there were no significant differences.

The basic descriptive statistics and analysis results for male and female patients are presented in Table 5. The results show no statistically significant differences between all paired independent samples' t-test results according to gender.

The distribution of the ABD between the femur and tibia is presented in Figure 1. From this figure, it can be seen that 93.84% of the femur rotation was ≤15° and 96.99% of the tibia rotation was ≤15°.

Discussion

One of the most important clinical implications of this study is the absence of significant gender-based differences in femoral and tibial rotation. This demonstrates that clinicians can use the same reference values when assessing patients, regardless of gender. With this in mind, this approach could potentially provide a more standardized approach, simplifying diagnosis and treatment planning.

Table 1. General descriptive statistics and comparisons by gender

	Gender					
	Male (n=113) Mean (SD)	Female (n=17) Mean (SD)	All (n=130) Mean (SD)	p-value	95% CI	
Age	55.8 (15.15)	56.4 (14.90)	55.9 (15.06)	0.9780	-8.33	7.23
Femoral rotation	12.2 (7.12)	13.3 (7.38)	12.3 (7.13)	0.5052	-4.77	2.59
Tibial rotation	31.3 (9.76)	34.9 (10.52)	31.8 (9.90)	0.0887	-8.71	1.45

CI: Confidence interval, SD: Standard deviation

Table 2. Pearson's correlation coefficient between right and left lower extremities

	r	p-value	95% CI	
Femoral rotation	0.59	<0.0001	0.46	0.69
Tibial rotation	0.76	<0.0001	0.68	0.82

CI: Confidence interval

Table 3. Comparison of right and left lower extremity measurements

	Right (n=130) mean (SD)	Left (n=130) mean (SD)	RBD mean (SD)	ABD mean (SD)	p-value RBD	95% CI RBD	
Femoral rotation	12.62 (8.26)	12.05 (7.73)	0.57 (7.24)	5.11 (5.14)	0.3721	-0.68	1.82
Tibial rotation	32.93 (10.43)	30.65 (10.63)	2.28 (7.18)	5.19 (5.45)	0.0004	1.03	3.53

CI: Confidence interval, ABD: Absolute bilateral difference, RBD: Relative bilateral difference, SD: Standard deviation

Table 4. Comparison of right and left lower extremity measurements according to gender

	Gender	Right (n=130) mean (SD)	Left (n=130) mean (SD)	RBD mean (SD)	ABD mean (SD)	p-value RBD	95% CI RBD	
Femoral rotation	Male	12.54 (8.21)	11.84 (7.79)	0.70 (7.32)	5.13 (5.25)	0.3086	-0.66	2.06
	Female	13.12 (8.78)	13.45 (7.41)	-0.34 (6.77)	4.97 (4.44)	<0.0001	-3.28	-1.65
Tibial rotation	Male	32.56 (10.46)	35.35 (10.16)	2.50 (7.27)	5.17 (5.68)	0.7899	-1.36	1.76
	Female	30.06 (10.37)	34.52 (11.81)	0.83 (6.58)	5.31 (3.74)	0.6101	-2.55	4.21

CI: Confidence interval, ABD: Absolute bilateral difference, RBD: Relative bilateral difference, SD: Standard deviation. External rotation is shown as positive values; concurrently internal rotation is shown as negative values

Table 5. Basic descriptive statistics and analysis results for male and female patients

	Gender				
	Male (n=113) mean (SD)	Female (n=17) mean (SD)	p-value	95% CI	
Femoral rotation (right)	12.5 (8.21)	13.1 (8.78)	0.6837	-4.84	3.69
Femoral rotation (left)	11.8 (7.79)	13.5 (7.41)	0.3459	-5.60	2.37
RBD of the femoral rotation	0.7 (7.32)	-0.3 (6.77)	0.8305	-2.69	4.77
ABD of femoral rotation	5.1 (5.25)	5.0 (4.44)	0.8063	-2.50	2.81
Tibial rotation (right)	32.6 (10.46)	35.4 (10.16)	0.1555	-8.16	2.57
Tibial rotation (left)	30.1 (10.37)	34.5 (11.81)	0.0671	-9.90	0.97
RBD of the tibial rotation	2.5 (7.27)	0.8 (6.58)	0.6736	-2.03	5.37
ABD of tibial rotation	5.2 (5.68)	5.3 (3.74)	0.3436	-2.96	2.68

CI: Confidence interval, ABD: Absolute bilateral difference, RBD: Relative bilateral difference, SD: Standard deviation. External rotation is shown as positive values; concurrently internal rotation is shown as negative values

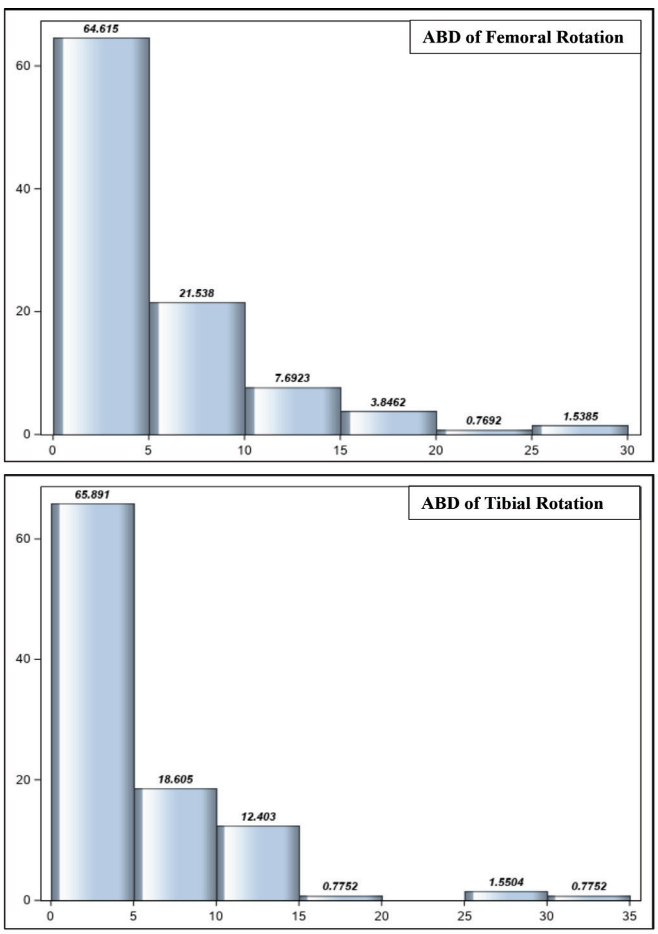

Figure 1. Distribution of absolute bilateral rotation difference between the femur and tibia
ABD: Absolute bilateral difference

Another important finding of our study was the rotational symmetry between the right and left extremities, which correlated moderately with femoral rotation and highly with tibial rotation. This symmetry provides a valuable reference point for orthopedic surgeons, allowing them to more precisely identify rotational abnormalities and make more informed decisions regarding surgical interventions or conservative treatments.

The fact that right tibial rotation is significantly more outwardly rotated than left tibial rotation is an important clinical implication to consider, especially in the treatment of conditions such as tibial torsion. This asymmetry can lead to functional and biomechanical consequences that may have implications for surgical planning and postoperative rehabilitation. Therefore, clinicians can tailor treatment plans to the specific needs of each patient while considering rotational differences.

In a study by Kinami et al. (9) in healthy Japanese subjects, remarkable bilateral symmetry in rotation of the femur and tibia was observed, with mean ABD of 6.5° and 5.1°, respectively. Furthermore, 95% of femoral rotation was within ≤15° US, while 89% of tibia rotation was within ≤10° US (9). The current study, together with our previous one, provides a basis for understanding the nuances of lower extremity rotational alignment. In our study, we examined the rotation of the femur and tibia in a different cohort and found mean values of 12.2° and 31.3°, respectively. In contrast to the Japanese study, our data revealed no significant rotational differences between genders. Both studies emphasize the importance of considering IBDs during surgical interventions to avoid potential functional impairments. While the Japanese study highlighted the tendency for higher external rotation on the right side, especially during tibial surgery, our study emphasizes the importance of accurate intraoperative assessments to avoid significant malrotation.

Another study by Ries et al. (10) aimed to establish reference values for lower extremity rotation in a healthy population and revealed significant side-to-side asymmetry in femorotibial torsion. The left femur showed greater anteversion and the right tibia showed more external rotation (10). This finding is important for clinical applications, particularly in the diagnosis and treatment of rotational deformities. Similarly, Zheng et al. (11) found significant individual differences in femoral and tibial torsion between patients with bilateral varus-type knee OA and controls, emphasizing the need for caution when assessing rotational alignment in such patients. Gallo et al. (12) also emphasized the variability in tibial torsion, reporting that 12.3% of patients had IBDs of ≥10 degrees and that race/ethnicity affected the magnitude of torsion but not the IBDs.

Ivanov et al. (13) compared three fluoroscopic methods for identifying femoral rotation and found that the true lateral and neck-horizontal angle techniques were more reliable than the smaller trochanter profile method, resulting in more significant malrotation.

Finally, Roberts et al. (14) validated the intermalleolar method for intraoperative assessment of tibial rotation during intramedullary nail fixation and demonstrated its accuracy to be 10° within CT measurements. These studies emphasize the importance of recognizing IBDs in femorotibial rotation and the need for precise measurement techniques to ensure correct rotational alignment during orthopedic procedures.

The strengths of this study include the fact that it was performed in a large patient population and the use of CT angiography and venography methods for the evaluation of femur and tibia rotations. The high accuracy of the data increases the reliability of the findings. In addition, the diversity of experience levels of the orthopedic surgeons involved in the study ensured that the measurements were performed in an independent and unbiased manner.

Study Limitations

The study has some limitations. The retrospective design and single-center nature of the study may limit the generalizability of the results. The relatively homogeneous study population was relatively homogeneous and did not include individuals with different ethnicities or underlying pathologies suggests that the results may not apply to all patient groups. An increased study size and an equally balanced gender ratio could have been determined if the study were not planned as a retrospective study. Furthermore, the lack of long-term follow-up data limits the assessment of the long-term effects of rotational variations on lower limb function. In future studies, large-scale investigations with more diverse populations and long-term follow-up data are recommended.

Conclusion

In conclusion, this study provides valuable insights into the variations in femur and tibial rotation in the lower extremities. The findings have important clinical implications that may help clinicians make more informed decisions when evaluating and treating patients. However, further research is required before these findings are fully integrated into clinical practice. In particular, understanding the long-term effects of rotational variations on lower limb function and the underlying mechanisms of these variations are important areas for future research.

Ethics Committee Approval: The University of Health Sciences Turkey, İstanbul Training and Research Hospital Ethics Committee approved the study (approval number: 76, date: 09.08.2024).

Informed Consent: Informed consent was obtained through an "opt-out" form available on the hospital website.

Authorship Contributions: Concept - A.Ç.; Design - A.Ç., B.A., İ.T.A.; Data Collection or Processing - A.Ç., Ö.D.G., E.K., İ.T.A.; Analysis or Interpretation - A.Ç., İ.T.A.; Literature Search - A.Ç., B.A., Ö.D.G., E.K.; Writing - A.Ç., İ.T.A.

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