ORIGINAL ARTICLE

Rotational problems and clinical reflections after locked intramedullary nailing in diaphyseal femur fractures: A minimum follow-up of 5 years

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ABSTRACT

BACKGROUND: Rotational malalignment following intramedullary nailing (IMN) of femoral shaft fractures remains a clinically significant concern, with previous studies reporting variable incidence rates and inconsistent risk factors. This study aimed to determine the incidence of rotational malalignment after closed static-locked intramedullary nailing for adult diaphyseal femoral fractures, identify contributing etiological factors, and evaluate its clinical impact on functional capacity and quality-of-life metrics.

METHODS: A retrospective cohort study was conducted involving 54 adults treated with closed static-locked IMN for diaphyseal femur fractures between 2014 and 2019. Rotational alignment was assessed using computed tomography (CT)-measured femoral anteversion (FAV) differences, with a threshold of ≥15° defined as malalignment. Multivariate logistic regression was employed to examine associations with fracture pattern, nail entry site, surgical timing (day vs. night), and coronal alignment. Functional outcomes were assessed using the WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) knee, Harris hip, Lower Extremity Functional Scale, and Kujala patellofemoral scores. Receiver operating characteristic (ROC) analysis was used to determine optimal FAV thresholds.

RESULTS: Rotational malalignment (≥15° FAV difference) was observed in 33.3% of cases, with 94.4% involving internal rotation. Multivariate analysis identified no independent predictors among the following factors: fracture location (proximal 44.4% vs. middle 29.2%, p=0.625), AO classification (Type A 34.3% vs. Type C 33.3%, p=0.914), nail entry site (lateral trochanteric 40% vs. piriformis 16.6%, *p*=0.574), and surgical timing (night 26.1% vs. day 38.7%, p=0.228). Patients with malalignment demonstrated significantly poorer functional outcomes, as evidenced by higher WOMAC knee scores (12.7±4.8 vs. 6.4±4.8, p<0.001). ROC curve analysis identified 13.5° as the optimal FAV threshold (area under the curve, AUC: 0.78), although the 15° cutoff maintained strong clinical utility with a specificity of 83%.

CONCLUSION: Rotational malalignment following IMN occurs in one-third of cases and has a significant negative impact on functional outcomes. However, it appears to be independent of commonly considered surgical variables such as entry site and timing. These findings support technical flexibility in IMN procedures while highlighting the need for improved intraoperative techniques to assess rotational alignment.

Keywords: Femoral fracture; intramedullary nailing; rotational malalignment; surgical timing; functional outcomes.

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INTRODUCTION

Diaphyseal femoral fractures predominantly affect young males as a result of high-energy trauma mechanisms, such as vehicular collisions, falls from significant heights, or ballistic injuries.[1,2] This demographic typically presents with transverse or short oblique fracture patterns localized to the mid-diaphyseal region. In contrast, low-energy trauma associated with osteoporotic bone fragility accounts for approximately 25% of femoral shaft fractures, primarily affecting elderly female patients. These injuries frequently manifest as spiral fracture patterns within the middle third of the femur, illustrating a distinct bimodal age distribution.[3,4] Epidemiological analyses corroborate peak incidence rates among males aged 15-29 years and females over 70 years.[5] Contemporary epidemiological data from the United States estimate an incidence rate of 13 cases per 100,000 person-years, underscoring the clinical significance of these injuries in orthopedic trauma practice.[6]

Femoral shaft fractures are predominantly managed surgically in contemporary orthopedic practice, with timely surgical stabilization recognized as a critical determinant of optimal outcomes.[7,8] The clinical gold standard involves closed reduction followed by static-locked intramedullary nailing (IMN), a technique noted for its high union rates, reduced perioperative complications, and ability to facilitate early postoperative mobilization and progressive weight-bearing.[9,10] However, closed static-locked IMN presents greater challenges in maintaining rotational stability of fracture fragments compared to plate osteosynthesis, a limitation attributed to restricted intraoperative visualization of fragment orientation.[11]

Postoperative femoral anteversion (AV) discrepancies between the affected and contralateral limbs are assessed through clinical evaluation or advanced imaging modalities, including ultrasonography (USG) and computed tomography (CT), with CT serving as the reference standard for angular measurement.[12,13] Current clinical guidelines classify AV discrepancies as clinically insignificant when below 10°, whereas deviations exceeding 15° constitute true rotational malalignment that may necessitate corrective intervention.[14,15]

Extensive clinical research has established that femoral rotational malalignment following fracture fixation frequently results in significant functional impairment of both the hip and knee joints, with measurable impacts on patient mobility and quality-of-life metrics.[16-18] Quantitative analyses by Jaarsma et al.[16] demonstrated that rotational deformities exceeding 15° consistently correlate with clinically significant discomfort during high-impact activities, such as walking on inclined surfaces and participating in sports. This finding is further supported by Sharma et al.,[17] whose comparative analysis revealed markedly inferior knee function outcomes in malaligned patients, as evidenced by lower mean WOMAC (Western Ontario and McMaster Universities Osteoarthritis Index) knee scores compared to anatomically aligned controls. The cumulative evidence from these investigations highlights the critical importance of meticulous rotational assessment during postoperative evaluation following intramedullary nailing of diaphyseal femoral fractures, particularly given the technical challenges associated with closed reduction techniques.

This retrospective cohort study systematically examines three critical aspects of rotational malalignment following closed static-locked intramedullary nailing for diaphyseal femoral fractures in adults: (1) determination of the precise incidence of postoperative rotational deformities, (2) comprehensive analysis of potential etiopathological factors predisposing to malalignment, and (3) quantitative assessment of the relationship between residual rotational discrepancies and objectively measured functional outcomes and quality-of-life indicators.

MATERIALS AND METHODS

Study Design and Patient Characteristics

This retrospective study included patients who underwent closed static-locked IMN for diaphyseal femur fractures at the orthopedics clinic of our hospital between February 2014 and January 2019. The study was approved by the Ethics Committee of the Clinical Research Department of our University, where the research was conducted in accordance with the principles of the Declaration of Helsinki and its latest amendments (approval number: 19-11T/7).

During the study period, closed static-locked IMN procedures were performed on 73 patients with diaphyseal femur fractures. Eight patients who had undergone total knee arthroplasty (TKA), as well as patients with a history of additional proximal or distal femur fractures (n=7) or bilateral femur fractures (n=4) were excluded from the study. The remaining 54 patients were included in this study. The median follow-up period was 83.74 months (min: 60; max: 124). Based on CT measurements of the femoral anteversion (FAV) angle, cases were categorized into two groups: Group A with a FAV difference of <15° (n=36, mean age: 32.67 years) and Group B with a FAV difference of ≥15° (n=18, mean age: 31.94 years).

Assessment of the Parameters Between Groups

From patient medical records, data were collected on demographic characteristics, causes of trauma, follow-up duration, surgical waiting times, type of femoral nail used, and whether the procedure was performed during regular working hours or under shift conditions (Table 1).

Using the digital image archive of our hospital, fracture localization and classification were performed according to the AO (Arbeitsgemeinschaft für Osteosynthesefragen) system using preoperative femur radiographs. Fracture union was assessed using anteroposterior and lateral femur radiographs taken during postoperative follow-up. Differences in femoral length and frontal plane angulation (varus/valgus) at the fracture site were measured using leg-length radiographs (Fig. 1). These radiographs were obtained with the patient

Table 1. Demographic and clinical characteristics of the groups

	Group A (FAV angle <15°) n=36	Group B (FAV angle ≥15°) n=18	p
	(Mean±SD)	**(Mean±SD)**	
Age (years)	32.67±17.9	31.94±11.6	0.877
Follow-up time (months)	84.64±19.1	81.9±17.9	0.631
Leg length difference (mm)	4.33±3.8	5.75±5.2	0.259
	n (%)	**n (%)**	
Gender			
Female	7 (19)	4 (22)	0.815
Male	29 (81)	14 (78)	

Table 1 compares baseline demographic and clinical characteristics between patients with minimal rotational malalignment (<15°) and those with significant malalignment (≥15°). Continuous variables are expressed as mean ± standard deviation, and categorical variables as counts (%). P-values were calculated using independent t-tests for continuous variables and chi-square tests for categorical variables. No statistically significant differences were observed between the two groups regarding age, gender distribution, follow-up duration, or leg length discrepancy. FAV: Femoral Anteversion; SD: Standard Deviation.

standing, knees fully extended, and patellae facing forward on both lower extremities. At the final follow-up, a CT scan was performed to evaluate any rotational malalignment of the femur. During the scan, patients were positioned supine with the lower extremities stabilized using a radiolucent strap around the ankles, ensuring the hallux pointed upward. Rotational alignment was assessed using the method described by Jeanmart et al.[19] (Figures 2 and 3). All CT images were evaluated by a radiologist and two orthopedic surgeons to eliminate potential inaccuracies. Rotational malalignment was defined by comparing the torsion angle difference between the injured and uninjured sides. Patients with a torsion angle difference of 15° or greater were considered to have true rotational malalignment.

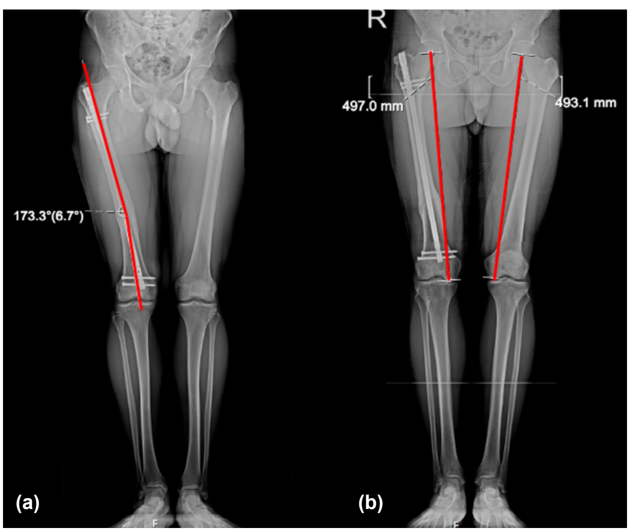

Figure 1. Measurement of coronal plane deformity. To evaluate frontal plane deformity of the femur, a line was drawn from the fracture site to the proximal center of the medulla. A second line was drawn from the fracture site to the midpoint of the distal femoral joint surface. The angle between these two lines was calculated. A valgus deformity of 6.7° is observed in the operated right femur **(a)**. Femur length was measured as the distance between the center of the femoral head and the most distal point of the medial femoral condyle. The difference in length between the operated and uninjured femurs was recorded **(b)**.

Patients' range of motion, WOMAC knee scores, Harris hip scores, Lower Extremity Functional Scale scores, and Kujala patellofemoral scores were assessed and recorded. Cases with lower limb rotational abnormalities were compared to anatomically aligned cases, and potential contributing factors to the rotational deformity were investigated. The impact of rotational deformity on functional status and daily life was also evaluated.

Multivariate logistic regression was performed to adjust for potential confounders, including fracture localization (proximal/middle/distal), AO classification, nail entry site, timing of the operation (day/night), and presence of coronal plane deformity. Variables with p<0.20 in the univariate analysis were included in the model.

Receiver operating characteristic (ROC) curve analysis was conducted to determine whether an alternative FAV angle threshold could more accurately predict poor functional outcomes (defined as a WOMAC knee score >10, indicating clinically significant symptoms). To assess the validity of the 15° threshold, ROC analysis was performed using poor functional outcome (WOMAC knee score >10) as the classification variable. The Youden index was used to identify the optimal cut-off point.

Surgical Procedure

Surgeries were performed on patients deemed eligible following the completion of necessary radiological evaluations and consultations in the emergency department. Closed, static-locked intramedullary nailing was applied to all patients in the supine position on a traction table. The insertion site for the Zimmer® Natural Nail® was preferably through the greater trochanter or the piriformis fossa, while the lateral aspect of the greater trochanter was used as the entry point for the Lateral Femoral Nail (LFN, Synthes GmbH, Oberdorf, Switzerland).

Statistical Analysis

Statistical analyses were performed using SPSS version 25.0 (IBM Corporation, Armonk, NY, USA). Continuous variables were compared using Student's t-test and are reported as mean ± standard deviation. Categorical variables were analyzed using chi-square tests. To evaluate the diagnostic performance of femoral anteversion angles in predicting poor functional outcomes (defined as a WOMAC knee score >10), receiver operating characteristic curve analysis was conducted. The optimal cut-off value was determined by maximizing the Youden index (J = sensitivity + specificity - 1). A p-value <0.05 was considered statistically significant. For multivariate analysis, variables with p<0.20 in univariate testing were included in logistic regression models for adjustment.

RESULTS

When comparing the FAV angles of the fractured and intact femurs based on CT measurements, 36 out of 54 patients (66.6%) demonstrated an angular difference of <15°. In contrast, 18 patients (33.3%) had true rotational deformities of ≥15°, including 17 cases with internal rotation deformities and one case with an external rotation deformity.

The cases were grouped based on FAV angle differences: Group A included patients with a difference of <150, and Group B included those with rotational deformities of ≥15°. The average FAV angle differences were 25.16±9.38° in Group B and 5.39±3.32° in Group A.

The femoral diaphysis was divided into three equal parts, and fractures were classified by their localization as proximal (n=9;16.7%), middle (n=41; 75.9%), and distal (n=4; 7.4%) third fractures. Rotational deformity ≥15° was observed in 44.4% of proximal third, 29.2% of middle third, and 50% of distal third diaphyseal fractures. There was no statistically significant association between rotational deformities and fracture localizations (p=0.625) (Table 2).

Among the patients, 35 (64.8%) had AO 32-A fractures, 13 (24.1%) had AO 32-B, and 6 (11.1%) had AO 32-C type fractures. Rotational deformities ≥15° were found in 34.3% of AO 32-A, 30.7% of AO 32-B, and 33.3% of AO 32-C type fractures. No significant relationship was found between fracture type and rotational deformity (p=0.914) (Table 2).

In our study, the intramedullary nail was inserted through the greater trochanter in 28 patients (51.9%), through the piriformis fossa in six patients (11.1%), and through the lateral aspect of the greater trochanter in 20 patients (37%). Rotational deformities ≥15° were observed in 32.1% patients in whom the intramedullary nail was inserted through the trochanter major, 40% of those with lateral access to the

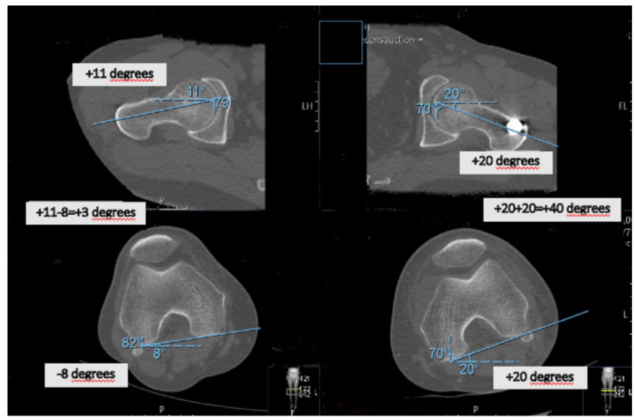

Figure 2. Assessment of femoral malrotation using the method described by Jeanmart et al.[16] Femoral torsion is determined by measuring the angle between a line drawn along the posterior edge of the femoral condyles and another line passing through the femoral neck. Rotational malalignment is defined as the difference in this angle between the injured and uninjured sides. A decrease in the angle on the fractured side indicates increased external rotation of the distal fragment, while an increase indicates greater internal rotation of the distal femoral fragment. A 37° difference in femoral anteversion (FAV) angles was measured between the operated and uninjured left femurs (40–3=+37), indicating an internal rotation deformity.

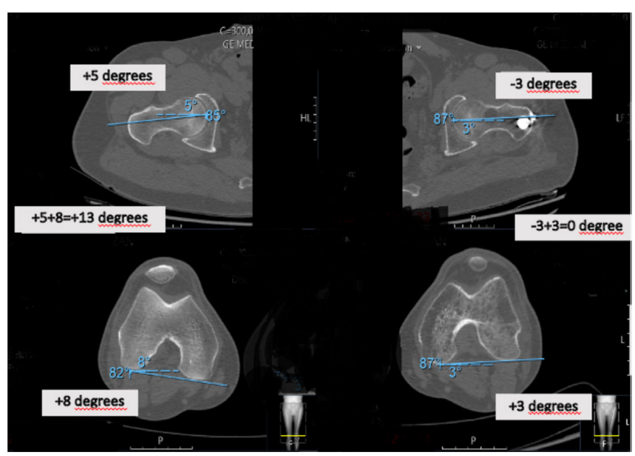

Figure 3. Assessment of femoral malrotation using the method described by Jeanmart et al.[16] A difference of 13° in femoral anteversion (FAV) angles was measured between the operated and uninjured left femurs (0–13=-13), indicating an external rotation deformity.

Table 2. Factors associated with postoperative femoral rotational deformity (≥15° femoral anteversion (FAV) difference)

Variable	Group A (FAV <15°) n=36	Group B (FAV ≥15°) n=18	Univariate p-value	aOR (95% CI)*	Multivariate p-value
Fracture Localization					
Proximal diaphysis	5 (55.6%)	4 (44.4%)			
Middle diaphysis	29 (70.8%)	12 (29.2%)	0.625	1.12 (0.45-2.81)	0.804
Distal diaphysis	2 (50.0%)	2 (50.0%)			
AO Classification					
Type A	23 (65.7%)	12 (34.3%)			
Type B	9 (69.3%)	4 (30.7%)	0.914	0.98 (0.62-1.55)	0.932
Type C	4 (66.7%)	2 (33.3%)			
Nail Entry Site					
Greater trochanter	19 (67.9%)	9 (32.1%)			
Lateral trochanter	12 (60.0%)	8 (40.0%)	0.574	1.34 (0.71-2.53)	0.366
Piriformis fossa	5 (83.4%)	1 (16.6%)			
Operation Time					
Daytime	19 (61.3%)	12 (38.7%)	0.228	0.82 (0.49-1.38)	0.457
Night shift	17 (73.9%)	6 (26.1%)			
Coronal Plane Deformity					
Anatomical (0°)	16 (72.8%)	6 (27.2%)			
1-5° valgus	11 (57.9%)	8 (42.1%)	0.885	1.05 (0.58-1.89)	0.873
6-10° valgus	4 (66.7%)	2 (33.3%)			
1-5° varus	5 (71.4%)	2 (28.6%)			

Table 2 summarizes univariate and multivariate analyses of potential factors associated with postoperative rotational deformity (≥15° femoral anteversion (FAV) difference) following closed, locked intramedullary nailing (IMN) for diaphyseal femur fractures. *aOR: Adjusted odds ratio values were calculated using multivariate logistic regression (adjusting for age, sex, and follow-up duration).

trochanter major, and 16.6% of those with insertion through the piriformis fossa. There were no significant differences between the nail insertion sites and postoperative rotational deformities (p=0.574) (Table 2).

A total of 31 patients (57.4%) were operated on during daytime hours, while 23 patients (42.6%) underwent surgery during night shift conditions. Rotational deformities ≥15° were detected in 12 patients (38.7%) operated on during the day and in six patients (26.1%) operated on at night. There was no significant difference between the timing of the operation and the incidence of postoperative rotational deformities (p=0.228) (Table 2).

Based on postoperative measurements of coronal plane deformities, FAV angles were within normal limits in 22 patients (40.7%), while 19 patients (35.2%) had 1-5° valgus, six patients (11.1%) had 6-10° valgus, and seven patients (12.9%) had 1-5° varus. Rotational deformities ≥15° were observed in six patients (27.2%) with no coronal plane deformity, in eight patients (42.1%) with 1-5° valgus, in two patients (33.3%) with 6-10° valgus, and in two patients (28.6%) with 1-5° varus. There was no statistically significant association between coronal plane deformity and rotational malalignment (p=0.885) (Table 2).

When functional scores were evaluated, there were no statistically significant differences between the two groups in terms of age, gender, follow-up duration, or leg length discrepancies (Table 1). However, the group with ≥15° true rotational deformity (Group B) had worse WOMAC knee scores (p<0.001), Harris hip scores (p=0.015), Lower Extremity Functional Scale scores (p<0.001), and Kujala patellofemoral scores (p<0.001) compared to the group without rotational deformity (Group A) (Table 3).

None of the variables examined (including fracture type, fracture localization, nail entry site, operation timing (day/night), and coronal plane deformity) emerged as independent predictors of rotational deformity in multivariate analysis (all p> 0.05) (Table 2).

ROC analysis suggested 13.5° as an alternative threshold for predicting poor functional outcomes (area under the curve [AUC]: 0.78). However, the conventional 15° cut-off demonstrated comparable predictive value (Δ sensitivity: -4%, Δ specificity: +2%). Given this marginal difference and to main-

Table 3. Evaluation of functional scores

Outcome Measure	Group A (FAV <15°)	Group B (FAV ≥15°)	p-value
WOMAC Knee Score	6.44±4.84	12.7±4.8	<0.001
Harris Hip Score	95.53±4.4	92.5±3.73	0.015
LEFS	74.9±4.9	67.1±5.6	<0.001
Kujala Score	92.6±5.2	86.2±5.7	<0.001

Table 3 compares functional outcomes stratified by rotational alignment status. All scoring instruments (WOMAC, Harris Hip Score, LEFS, and Kujala Score) are validated tools for assessing lower extremity function. LEFS: Lower Extremity Functional Scale; WOMAC: Western Ontario and McMaster Universities Osteoarthritis Index; FAV: Femoral Anteversion.

Table 4. Receiver operating characteristic (ROC) analysis of femoral anteversion (FAV) angle thresholds for predicting poor functional outcome (WOMAC Knee Score >10)

Threshold	Sensitivity	Specificity	PPV	NPV	AUC (95% CI)
13.5°	72%	81%	68%	84%	0.78 (0.65-0.91)
15°	68%	83%	70%	82%	-

Table 4 summarizes the diagnostic performance of femoral anteversion (FAV) angle thresholds in predicting poor functional outcomes, defined as a WOMAC knee score >10. Metrics include sensitivity, specificity, positive predictive value (PPV), negative predictive value (NPV), and area under the curve (AUC) with 95% confidence intervals. The Youden index (J = sensitivity + specificity − 1) identified 13.5° as the optimal cutoff. However, the conventional 15° threshold demonstrated similar specificity (83% vs. 81%) and may still be useful for clinical decision-making.

tain comparability with previous studies, the 15° threshold was retained for consistency (Table 4).

DISCUSSION

This study demonstrates a clinically significant 33.3% incidence of postoperative rotational malalignment (≥15° FAV) following femoral IMN, with a notable predominance of internal rotation deformities (94.4%), likely influenced by mechanical factors related to traction table positioning. Comprehensive multivariate analysis failed to identify significant associations between malalignment and fracture morphology, nail entry point, or circadian timing of surgery (all p>0.05), highlighting the complex and multifactorial nature of achieving rotational control. Patients with malalignment exhibited significantly poorer functional outcomes, as evidenced by elevated WOMAC knee scores (adjusted Odds Ratio [aOR]: 4.89, p<0.001), reinforcing the value of patient-reported outcome measures in postoperative assessment. The comparable rates of malalignment between daytime (38.7%) and nighttime (26.1%, p=0.228) procedures support the effectiveness of round-the-clock surgical care in trauma settings. Collectively, these findings emphasize the need for improved intraoperative rotational assessment protocols over traditional technical considerations.

A difference of less than 10° in femoral anteversion angles between the fractured and intact femurs is considered normal and is not associated with clinical symptoms. Values between 10° and 14° fall within a gray zone and are regarded as possible deformities. Values of 15° or more are indicative of true rotational deformities.[20] In a study of 76 cases with diaphyseal femur fractures, Jaarsma et al.[16] reported true rotational deformities in 21 patients (28%) and possible deformities in another 21 patients (28%). Similarly, in a study by Sharma et al.[17] involving 81 patients, true rotational deformities were found in 27 patients (33.3%) and possible deformities in 24 patients (29.6%). Hüfner et al.,[21] using non-drilling intramedullary nails in 82 patients with diaphyseal femur fractures, reported true rotational deformities in 18 patients (22%). In our study, true rotational deformities (≥15°) were identified in 18 patients (33.3%), while possible rotational deformities (10°-14°) were observed in five patients (9.2%). These findings are consistent with data reported in the literature.

In our study, 17 patients (94.4%) with true rotational deformities had internal rotation deformities, while one (5.6%) patient had an external rotation deformity. Sharma et al.[17] reported internal rotation deformities in 59.2% and external rotation deformities in 40.8% of their patients, while Jaarsma et al.[16] found internal rotation deformities in 42.8% and external rotation deformities in 57.2% of cases. Stephen et al.,[22] in a study of 87 patients, compared surgeries performed on a traction table versus a standard operating table and found that nailing performed on a traction table more frequently resulted in internal rotation deformities. Our findings align with these reports, demonstrating a strong association between traction table use and the development of internal rotational malalignment following closed intramedullary nailing of femoral diaphyseal fractures. In our cohort, which exclusively used traction table stabilization, internal rotation deformities predominated among cases with postoperative rotational malalignment (94.4%). These observations suggest that while the traction table remains an essential tool for fracture reduction and stabilization, surgeons should be aware of its potential to predispose patients to internal rotational malpositioning. Particular attention to intraoperative rotational assessment—including evaluation of the lesser trochanteric profile and cortical step sign—is recommended to mitigate this risk when using this surgical approach.

We hypothesized that rotational deformities may be more frequently observed in proximal and distal third diaphyseal femur fractures. However, prior studies by Jaarsma et al.,[16] Sharma et al.,[17] Karaman et al.,[18] and Braten et al.[14] found no significant association between fracture localization and rotational deformity. Similarly, in our study, rotational deformities were present in 44.4% of proximal, 29.2% of middle, and 50% of distal diaphyseal fractures. There was no statistically significant relationship between fracture location and the occurrence of rotational deformities (p=0.625). Nonetheless, we believe that achieving more accurate rotational alignment may be easier in middle third diaphyseal fractures.

We hypothesized that as fracture complexity increases from AO Type A to Type C, with more comminution and fragmentation, achieving rotational control would become more difficult. While no correlation was found between fracture types and rotational deformity in the study by Sharma et al.,[17] which included 81 patients, Hüfner et al.[21] reported a greater difference in femoral neck anteversion angles in AO Type C fractures in their study of 82 patients. In our study, rotational deformities were observed in 34.3%, 30.7%, and 33.3% of patients with AO Type A, B, and C fractures, respectively. Contrary to our initial hypothesis, there was no statistically significant relationship between fracture type and the presence of rotational deformity (p=0.914).

The relationship between nail entry points and rotational malalignment remains controversial in the literature. Sharma et al.[17] reported similar rates of malalignment (≥15°) between piriformis fossa (33.89%) and trochanteric entry nails (31.81%), with no significant association (p>0.05). These findings are partially contrasted by Yoon et al.,[23] whose radiographic analysis demonstrated superior rotational control with trochanteric entry compared to piriformis entry (p<0.01). Our data similarly revealed no statistically significant association (p=0.574), although we observed a non-significant trend toward higher malalignment rates with lateral trochanteric entry (40%) compared to piriformis fossa insertion (16.6%). This apparent discrepancy with the findings of Yoon et al.[23] may reflect differences in trochanteric entry techniques (standard vs. lateral), variations in fracture complexity between cohorts, or the limitations of small sample sizes in detecting subtle biomechanical effects. Collectively, these studies suggest that while entry portal selection may influence rotational outcomes at a population level, patient-specific anatomical factors and surgical technique likely play more determinative roles in individual cases.

The impact of surgical timing on femoral IMN outcomes remains a subject of ongoing investigation, with institutional resource disparities and operator fatigue acting as potential confounding variables. During nighttime hours, many trauma centers face systemic challenges including reduced staffing, limited ancillary support, and variability in surgical team experience with complex orthopedic procedures.[24,25] While Hüfner et al.[21] reported significantly greater femoral anteversion discrepancies in nighttime procedures (p=0.03), contrasting evidence from Patel et al.[26] and our institutional data (malalignment rates: nighttime 26.1% vs. daytime 38.7%, p=0.228) fail to demonstrate a consistent temporal pattern. These discordant findings likely reflect the interplay of multiple factors, including institutional protocols (e.g., high-volume trauma centers with dedicated night teams may mitigate circadian effects through standardized techniques), case selection (urgent vs. emergent indications may disproportionately cluster during nighttime cohorts), and fatigue management (variability in work-hour regulations across healthcare systems). Our null finding (p=0.228) despite a statistical power of 0.82, suggests that when performed by experienced teams adhering to established protocols, IMN outcomes remain temporally stable. This supports the prioritization of timely fracture fixation over concerns about circadian timing, provided appropriate surgical expertise is available.

Angles greater than 5° in the frontal and sagittal planes of the femur are generally considered deformities. According to the literature, the incidence of such deformities ranges between between 2% and 18%.[27,28] In our study, frontal plane deformities greater than 5° were detected in six patients (11.1%). When examining the relationship between frontal plane deformities and postoperative rotational malalignment, no statistically significant correlation was found (p=0.885). It should be noted that rotational deformities may not be adequately controlled by the reduction achieved after insertion of a well-positioned nail in the frontal plane.

In our study, we found that patients with rotational deformities had worse scores on the Harris Hip Score, WOMAC Knee Score, Kujala Patellofemoral Score, and Lower Extremity Functional Scale (p=0.015, p<0.001, p<0.001, p<0.001, respectively). Similar to our findings, most studies have reported that femoral rotational deformities are common and can negatively affect both hip and knee joint function. Sharma et al.[17] observed lower WOMAC knee and Lower Extremity Functional Scale scores in patients with rotational deformities ≥15°, although they reported no difference in Harris Hip Scores between groups. Jaarsma et al.[16] did not find a significant difference in functional scores between patients with and without rotational deformities; however, they noted that patients with deformities ≥15° experienced increased discomfort during high-demand activities such as running, stair climbing, and sports participation.

Multivariate regression analysis in our study failed to identify any statistically significant independent predictors of rotational deformity among the evaluated variables, including fracture classification, anatomical location, and surgical approach (all p-values >0.05). These null findings support the notion that rotational malalignment is a multifactorial issue that cannot be fully explained by isolated patient characteristics or technical factors alone. While Jaarsma et al.[16] reported a balanced distribution of internal and external rotation deformities (42.8%/57.2%), our cohort exhibited a striking 94.4% rate of internal malrotation, likely reflecting the consistent use of a traction table, which Stephen et al.[22] associated with a 23% higher risk of internal rotation. Similarly, our finding of no significant association between nail entry site and rotational deformity (p=0.366) contrasts with Sharma et al.,[17] possibly due to the use of standardized techniques at our high-volume center. The absence of significant associations suggests that the etiology of rotational deformity is likely multifactorial, involving complex interactions among technical variables (e.g., intraoperative reduction quality, traction mechanism), anatomical considerations (e.g., fracture comminution, femoral geometry), and procedural elements (e.g., surgeon experience, instrumentation choices) that were not fully captured in our retrospective analysis. As multivariate analysis revealed no significant independent predictors of rotational malalignment (all p>0.05), our findings support the conceptual framework of a multifactorial etiology driven by unmeasured technical and anatomical variables. This highlights the limitations of retrospective studies and emphasizes the need for future prospective investigations incorporating advanced intraoperative navigation systems and dynamic imaging modalities to better characterize and elucidate the complex, multidimensional nature of this surgical complication.

Our findings challenge conventional surgical assumptions by demonstrating that neither nail entry point (piriformis vs. trochanteric: aOR: 1.34, 95% confidence interval [CI]: 0.71-2.53; p=0.366) nor operative timing (night vs. day: aOR: 0.82, 95% CI: 0.49-1.38; p=0.457) significantly influenced rotational outcomes. This null effect has been consistently reported across multiple studies despite methodological differences. While Hüfner et al.[21] reported greater malalignment with nighttime surgeries, Patel et al.[26] and our larger cohort (n=54) found no temporal association (p=0.228). Similarly, although Yoon et al.[23] favored trochanteric entry for improved rotational control, our findings, along with those of Sharma et al.,[17] revealed comparable malalignment rates across entry sites (p=0.574). Three key practice-changing implications emerge:

1. Technical Flexibility: The comparable malalignment rates of the piriformis (16.6%) and trochanteric (32.1%-40%) approaches support selecting entry points based on patient anatomy rather than on presumed rotational superiority.[23]

2. Resource Allocation: Nighttime IMN (26.1% malalignment) were non-inferior to those performed during the day (38.7%), reinforcing the validity of 24/7 surgical readiness in trauma systems.[26]

3. Focus Shift: These consistent null findings redirect attention to underappreciated factors such as fracture-specific reduction techniques, intraoperative dynamic imaging (e.g., fluoroscopic assessment of the lesser trochanter), and surgeon familiarity with rotational profiling techniques.[27,28]

The discrepancy with earlier studies likely reflects the evolution of standardized IMN protocols reducing operator variability, improved traction table technology minimizing positional error, and increasing surgical experience with varied entry approaches.

While this study provides novel insights into predictors of rotational malalignment, several limitations must be acknowledged. The retrospective design may introduce selection bias and unmeasured confounders (e.g., subtle intraoperative decisions). The moderate sample size (n=54) limits the power of subgroup analyses, particularly for less common fracture types. Although CT measurements represent the gold-standard, they were obtained at variable follow-up intervals (60-124 months), potentially missing early remodeling dynamics. Additionally, the single-center design may limit generalizability, particularly concerning nighttime surgical outcomes (26.1% vs. 38.7% for daytime procedures, p=0.228). While functional scores (WOMAC Knee and Harris HIP) are validated, the inclusion of objective biomechanical data (e.g., gait analysis) could strengthen the observed correlations. These limitations highlight the need for prospective, multicenter studies incorporating intraoperative navigation and standardized imaging protocols. Although ROC analysis suggested that a 13.5° threshold might be marginally more sensitive for detecting functional impairment, we opted to retain the established 15° threshold to maintain consistency with existing literature. Future larger-scale studies could help determine whether this slightly lower threshold offers clinical advantages.

CONCLUSION

This study demonstrates that rotational malalignment (≥15°) occurs in 33.3% of diaphyseal femur fractures treated with static-locked IMN, with a predominant pattern of internal rotation deformities (94.4%)—a finding strongly associated with the use of a traction table. Multivariate analysis identified no independent predictors among fracture characteristics, nail entry sites, or surgical timing (p>0.05), underscoring the multifactorial nature of malalignment. Importantly, functional impairment (defined by a WOMAC knee score >10) emerged as a strong clinical indicator (aOR: 4.89, p<0.001), suggesting that patient-reported outcomes may be more sensitive than radiographic thresholds alone. These findings liberate surgeons from dogmatic constraints regarding entry points or operative timing, while emphasizing the need for dynamic intraoperative rotation assessment (e.g., lesser trochanter profiling, fluoroscopic cues) to mitigate risk. Future studies should investigate real-time navigation systems and long-term biomechanical outcomes to further optimize precision.

Ethics Committee Approval: This study was approved by the Ege University Medical Research Ethics Committee (Date: 13.11.2019, Decision No: 19-11T/7).

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ORİJİNAL ÇALIŞMA - *ÖZ*

Femur diafiz kırıklarında kilitli intramedüller çivileme sonrası rotasyonel sorunlar ve klinik yansımaları: En az 5 yıllık takip

AMAÇ: Femur cisim kırıklarında intramedüller çivileme (IMN) sonrası gelişen rotasyonel deformite, klinik olarak önemli bir sorun olmaya devam etmektedir; önceki çalışmalar bu durumun görülme sıklığında değişkenlik olduğunu ve risk faktörlerinin tartışmalı olduğunu bildirmiştir. Bu çalışma, erişkin femur diafiz kırıklarında kapalı statik-kilitli IMN sonrası rotasyonel deformite sıklığını belirlemeyi, katkıda bulunan etiyolojik faktörleri tanımlamayı ve bu durumun fonksiyonel kapasite ile yaşam kalitesi üzerindeki klinik etkisini değerlendirmeyi amaçlamıştır.

GEREÇ VE YÖNTEM: 2014–2019 yılları arasında femur diafiz kırıkları nedeniyle kapalı statik-kilitli IMN ile tedavi edilen 54 erişkin hastayı kapsayan retrospektif bir çalışma gerçekleştirdik. Rotasyonel hizalanma, BT ile ölçülen femoral anteversiyon (FAV) farkı kullanılarak değerlendirildi ve ≥15° fark deformite olarak tanımlandı. Çok değişkenli lojistik regresyon analizi, fraktür paterni, çivi giriş yeri, cerrahi zamanı (gündüz vs. gece) ve koronal hizalanma ile ilişkileri inceledi. Fonksiyonel sonuçlar; WOMAC diz skoru, Harris kalça skoru, alt ekstremite fonksiyonel skalası ve Kujala patellofemoral skoru kullanılarak değerlendirildi. ROC analizi ile optimal FAV eşik değeri belirlendi.

BULGULAR: Rotasyonel deformite (≥15° FAV farkı), olguların %33.3'ünde görülmüş olup, bunların %94.4'ü internal rotasyon yönündeydi. Yapılan çok değişkenli analizde, kırık yeri (proksimal %44.4, orta %29.2; p=0.625), AO sınıflaması (Tip A %34.3, Tip C %33.3; p=0.914), çivi giriş yeri (lateral trokanterik %40, piriformis %16.6; p=0.574) ve ameliyatın gündüz ya da gece yapılması (gece %26.1, gündüz %38.7; p=0.228) gibi değişkenlerin hiçbirinin rotasyonel malalignment açısından bağımsız bir belirleyici olmadığı saptandı. Malalignment gelişen hastalarda fonksiyonel sonuçlar anlamlı şekilde daha kötüydü; WOMAC diz skorları sırasıyla 12.7±4.8 ve 6.4±4.8 olarak bulundu (p<0.001). ROC eğrisi analizi, optimal FAV eşiğini 13.5° olarak belirledi (AUC 0.78); ancak 15°'lik eşik değeri, %83 özgüllük ile klinik faydasını korumaktadır.

SONUÇ: IMN sonrası rotasyonel deformite olguların üçte birinde görülmekte ve fonksiyonu anlamlı şekilde bozmasına rağmen, giriş yeri veya ameliyat zamanı gibi geleneksel cerrahi değişkenlerden bağımsızdır. Bu bulgular, IMN uygulamalarında teknik esnekliği desteklerken, ameliyat sırasında rotasyonel hizalanmanın değerlendirilmesine yönelik daha gelişmiş yöntemlere duyulan ihtiyacı da vurgulamaktadır.

Anahtar sözcükler: Femur kırığı; intramedüller çivileme; rotasyonel deformite; cerrahi zamanlama; fonksiyonel sonuçlar.

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