Turkish Journal of Geriatrics
2025; 28(4):525–533

DOI: 10.29400/tjgeri.2025.469

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Received : Oct 25, 2025
Accepted: Dec 10, 2025

Cite this article as:
Aksoy A, Aslan A, Akdeniz HC. The Radiological Risk Factors Affecting Mechanical Failure in the Surgical Treatment with Proximal Femoral Nail of Intertrochanteric Fractures in Elderly Patients: a retrospective cohort study. Turkish Journal of Geriatrics 2025; 28(4):525–533.doi:10.29400/tjgeri.2025.469

ORIGINAL ARTICLE

THE RADIOLOGICAL RISK FACTORS AFFECTING MECHANICAL FAILURE IN THE SURGICAL TREATMENT WITH PROXIMAL FEMORAL NAIL OF INTERTROCHANTERIC FRACTURES IN ELDERLY PATIENTS: A RETROSPECTIVE COHORT STUDY

Abstract

Introduction: The aim of this study was to determine the rates of mechanical failure in patients who underwent proximal femoral nail fixation for intertrochanteric femur fractures, to identify the radiological risk factors for these failures, and to examine in particular the influence of the tip-apex distance and the femoral neck-shaft angle on treatment outcomes.

Materials and Method: A total of 90 patients who underwent proximal femoral nail fixation for intertrochanteric femoral neck fractures between 2019 and 2024 were retrospectively evaluated. Demographic, clinical, and radiological data were analyzed. The relationship between treatment success and the femoral neck-shaft angle and tip-apex distance was investigated. Statistical analyses included the Mann–Whitney U test, chi-square test, receiver operating characteristic curve analysis, and logistic regression.

Results: Mechanical failure occurred in 66.7% of the patients. In this group, the femoral neck-shaft angle was significantly higher (129.66 ± 7.20°, p=0.037), and the tip-apex distance value was greater (25.25 ± 8.37 mm, p=0.045). Receiver operating characteristic curve analysis revealed cutoff values of 119° for the femoral neck-shaft angle and 27 mm for the tip-apex distance.

Conclusion: The most important factors associated with treatment failure are improper implant positioning with an unfavorable femoral neck-shaft angle and an increased tip-apex distance. Maintaining the femoral neck-shaft angle within the range of 125°–130° and a tip-apex distance of less than 25 mm during surgical planning appears to improve success rates. However, these parameters alone are insufficient, and comprehensive evaluation of all contributing factors remains essential for clinical success.

Keywords: Bone Nails; Fracture Fixation; Hip Fractures; Prosthesis Failure; Treatment Failure.

INTRODUCTION

Low-energy hip fractures are often seen in patients aged over 60 years and are an important cause of morbidity and mortality (1, 2). As age and the prevalence of osteoporosis increase, there is also an increased frequency of intertrochanteric region fractures, which constitute a significant proportion of all hip fractures. These fractures are generally treated surgically (3). The application of Proximal Femoral Nail (PFN) is often the most preferred surgical treatment method because of the advantages that it can be applied with a minimally invasive technique and allows early mobilisation (4).

In addition to the advantages of PFN used in the surgical treatment of intertrochanteric region fractures, such as osteosynthesis, mechanical properties compatible with femur anatomy, and stability provided in the weight-bearing region, some disadantages have also been reported (5). The success of fracture treatment with PFN can be affected by many biological, biomechanical, and clinical factors. These factors include the type of fracture, nail design, the number of lag screws, tip-apex distance, blade type, reduction quality, the general condition of the patient, patient age, position of the screw and/or blade, experience of the surgeon, osteoporosis status, and bone quality (6). The most important factors affecting poor outcomes are malposition, screw migration, loss of fracture reduction, and implant failure (7). PFN failure occurring because of inability to meet the mechanical loading of the implant can lead to serious outcomes requiring revision surgery. Despite advances in PFN applications for intertrochanteric fractures, treatment is not successful in some elderly patients, and in these cases where PFN treatment is not successful, more invasive and expensive options may be required such as total hip arthroplasty (THA) (8). In the literature there is heterogenous information about the clinical and radiological results of PFN treatment of these fractures (6, 9-11).

The aim of this study was to comprehensively analyze the radiological factors affecting success in patients with intertrochanteric femur fracture treated with PFN.

METHOD

Study Inclusion and Exclusion Criteria

This retrospective study was conducted by examining the files of patients who underwent surgical treatment with PFN because of a femur intertrochanteric fracture in our hospital between 2019 and 2024. The study inclusion criteria were defined as patients with AO/OTA 31-A1, AO/OTA 31-A2, and AO/OTA 31-A3 type intertrochanteric femur fracture who underwent surgical treatment with PFN, had a follow-up period of at least 1 year, had postoperative radiographic records, and attended clinic follow-up appointments regularly. Patients were excluded from the study if they had a pathological fracture (eg. fracture due to malignancy), accompanying neurovascular injuries, open fractures, or if they were immobile.

The files were reviewed of 300 patients in our hospital with intertrochanteric region fracture within the specified dates. The results of 90 patients who met the study criteria were analyzed.

Ethical Approval

All procedures performed in studies involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki Declaration and its later amendments or comparable ethical standards. The study was approved by the Alanya Alaaddin Keykubat University Faculty of Medicine Clinical Research Ethics Committee, (Document date and number:11.12.2024/26-16). The procedures used in this study adhere to the tenets of the Declaration of Helsinki.

Surgical Technique

All the surgical procedures were performed with a standard protocol by a similar surgical team in the same centre. In the operative procedure, the fracture was reduced under C-arm fluoroscopy guidance, then fixated with a femur proximal femoral nail of appropriate length and diameter. For successful reduction and fixation, the criteria of femur neck-shaft angle of a minimum of 125°, and the tip-apex distance <25mm were taken into consideration.

Measurement Methods:

Two-way postoperative hip radiographs of all the patients were taken and recorded in the hospital digital records system. During the follow-up period, complications were recorded such as loss of the femur neck-shaft angle (varus angulation) or the development of cut-out (emergence of the screw or blade outside the femur head). Measurements of the TAD and femur neck-shaft angle were performed on the radiographs and recorded. Failure criteria were defined as varus collapse of the neck-shaft angle and subsequent cut-out.

In addition to radiological measurements, postoperative reduction quality and prognosis were also evaluated according to the Chang reduction criteria. Reduction was classified as good, acceptable, or poor based on alignment, fracture contact, and implant positioning on postoperative anteroposterior and lateral radiographs. This classification was used to further analyze its relationship with mechanical failure.

Statistical analysis

Data obtained in the study were analyzed statistically using SPSS vn. 27.0 software (IBM Corpn., Armonk, NY, USA). Descriptive statistics were stated as mean ± standard deviation (SD) , median, minimum and maximum values for continuous variables and number (n) and percentage (%) for categorrical variables. The conformity of numerical data to normal distribution was analyzed with the Kolmogorov-Smirnov test and the distribution was seen to be not normal. Therefore, the Mann Whitney U-test was used in the comparisons of two independent groups and the Kruskal-Wallis test was used in the comparisons of multiple groups. To determine relationships between categorical data, Monte Carlo Exact Chi-square analysis was applied. Receiver Operating Characteristic (ROC) analysis was performed to determine the diagnostic value of the tip-apex distance value. For 5% type-1 error rate in the analyses, a value of $p<0.05$ was accepted as statistically significant.

RESULTS

Evaluation was made of 90 patients, comprising 41.1% males and 58.9% females with a mean age of 78.02±15.38 years (median, 82.5 years; range, 19-101 years). The PFN treatment was successful in 33.3% of the patients and mechanical failure developed in 66.7%.

The demographic characteristics of the patients are presented in Table 1. According to the AO classfication, 52.2% of the patients had Type A1, and 47.8% had Type A2 fractures. The fractures were left-side in 54.4% of the patients and right-side in 45.6%. PFN was applied with a single screw in 77.8% of the patients and with a double screw in 22.2%.

Patients with traumatic etiology (traffic accident, earthquake, fall from bicycle) were observed only in the failure group ($p=0.015$). No significant difference was determined between the groups in respect of the other demographic variables (age, gender, height, weight, ICU admission, duration of operation) ($p>0.05$).

In the radiological findings, the neck-shaft angle was determined to be 129.66±7.20° in the failure group, and 122.47±15.84° in the successful group, and the difference was statistically significant ($p=0.037$). The TAD value was statistically

Table 1. Patient characteristics according to the success status after PFN operation

Variables	Categories	Failure	Success	p
		N (%)		
Nail number	Single	46 (76.7)	24 (80)	0.718
	Double	14 (23.3)	6 (20)	
Side	Left	33 (55)	16 (53.3)	0.881
	Right	27 (45)	14 (46.7)	
AO type	A1	32 (53.3)	15 (50)	0.765
	A2	28 (46.7)	15 (50)	
Gender	Male	25 (41.7)	12 (40)	0.880
	Female	35 (58.3)	18 (60)	
Etiology	Fall from standing	48 (80)	30 (100)	0.015*
	Traffic accident	5 (8.3)	0 (0)	
	Earthquake	6 (10)	0 (0)	
	Fall from bicycle	1 (1.7)	0 (0)	
ICU admission	No	26 (43.3)	17 (56.7)	0.232
	Yes	34 (56.7)	13 (43.3)	
		Mean±SD Median; Min-max		
Femur neck-shaft angle (degrees)		129.66±7.20 130.50; 108-144	122.47±15.84 125.90; 75.30-145	0.037**
Tip-apex distance(mm)		25.25±8.37 25.50; 8-44	21.43±8.34 22; 5-50	0.045**
Age (years)		75.71±17.25 81.50; 19-97	82.63±9.37 85; 58-101	0.108
Weight (kg)		71.91±13.47 73; 45-105	70.33±14.36 70; 40-95	0.655
Height (cm)		166.28±7.23 165; 150-183	163.23±8.05 160; 150-185	0.057
Length of stay in ICU (days)		1.65±2.42 1; 0-11	1.63±4.24 0; 0-23	0.300
Operation duration (hours)		1.98±1.78 2; 0-8	2.66±1.80 2.50; 0-7	0.062
Length of hospitial stay (days)		6.58±2.83 6; 2-16	9.30±7.23 7; 3-30	0.221

*: Level of statistical significance 0.05 according to the Chi-square analysis

**: Level of statistical significance 0.05 according to the Mann Whitney U-test significantly greater in the failure group (25.25±8.37 mm) than in the successful group (21.43±8.34 mm) (p=0.045).

In the subgroup analyses, the TAD values of patients applied with double screws were determined to be significantly higher in both the successful and groups (p<0.01). The angle values of patients with A1 type fracture in the failure group were observed to be at a significantly high level (p=0.026). The length of stay in hospital of females in the failure group was seen to be significantly prolonged (p=0.038). The angle values of patients in the failure group who were admitted to ICU were found to be significantly higher (p=0.017).

When the failure group was evaluated according to the Chang reduction criteria, the majority of patients demonstrated inadequate reduction characteristics, including insufficient medial cortical support, suboptimal alignment, and unfavorable implant positioning. In this group, a considerable proportion of patients also showed radiological risk factors such as increased tip–apex distance and non-optimal femoral neck–shaft angles, supporting the association between poor reduction quality and mechanical failure.

In the ROC analysis performed to predict the success status, the Area under the Curve (AUC) was determined to be 0.635 for the angle value (p=0.037), and 0.629 for TAD (p=0.046). At a cut-off value of 119° for the femur neck-shaft angle, sensitivity was found to be 36.7% and specificity 95%. A cut-off value of 27mm for TAD was determined to have 86.7% sensitivity and 48.3% specificity. (Figure 1. ROC curve for the angle value; Figure 2. ROC curve for the tip-apex distance).

In the logistic regression analysis, taking the patient group that resulted in failure as the reference, only the neck-shaft angle was determined

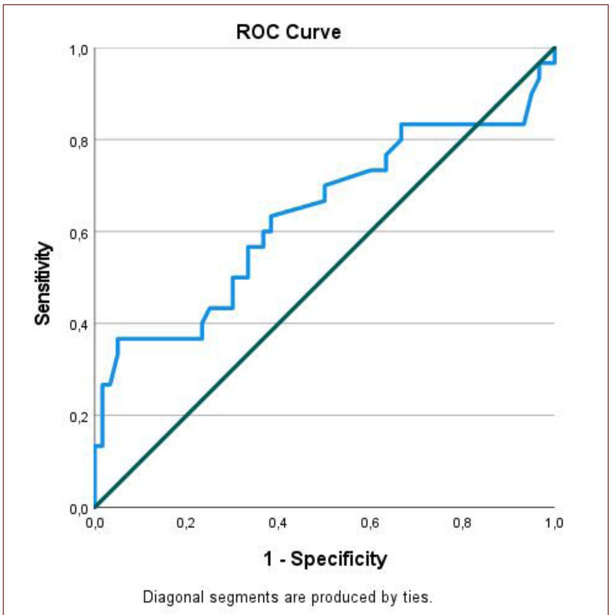

Figure 1. Receiver operating characteristic (ROC) curve of the femoral neck–shaft angle for predicting mechanical failure after proximal femoral nail fixation. The area under the curve (AUC) was 0.635 (p=0.037), with a cut-off value of 119° yielding 36.7% sensitivity and 95% specificity.

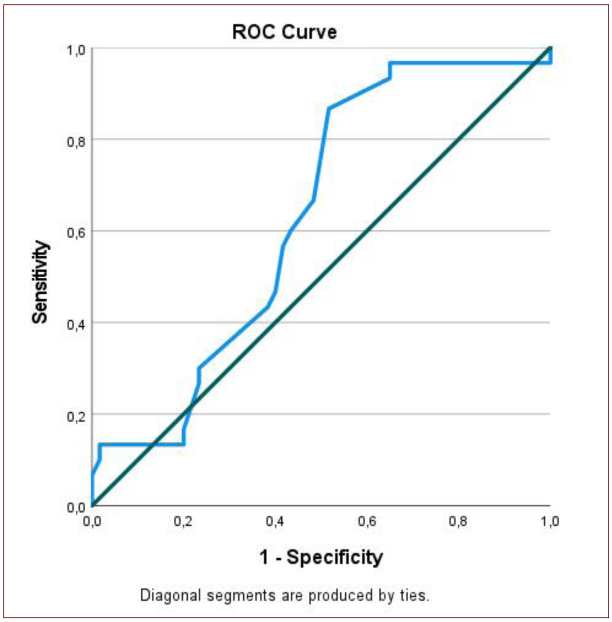

Figure 2. Receiver operating characteristic (ROC) curve of the tip–apex distance (TAD) for predicting mechanical failure after proximal femoral nail fixation. The area under the curve (AUC) was 0.629 (p=0.046), with a cut-off value of 27 mm yielding 86.7% sensitivity and 48.3% specificity.

Table 2. Factors affecting the PFN success status

Factors	Beta	p	OR	95% CI
Number of screws	0.216	0.716	1.241	0.387-3.977
Side	0.173	0.733	1.189	0.439-3.224
AO type	-0.084	0.867	0.920	0.345-2.450
Neck-shaft angle	-0.063	0.018*	0.939	0.891-0.989
Tip-apex distance	-0.051	0.106	0.951	0.894-1.011
Age	0.040	0.073	1.040	0.996-1.087
Gender	0.359	0.492	1.432	0.514-3.994
Fixed	5.019	0.203	151.20	

*:Level of statistical significance 0.05 according to the binary logistic regression analysis, Reference category:successful

to be statistically significant (OR=1.064, 95% CI: 1.011-1.122, p=0.014). An increase of each degree in the angle further decreased the probability of success. TAD and other variables were not found to be statisticaally significant (p>0.05). Only the angle value was included in the multivariate model and the statistical significance was preserved (OR=1.062, 95% CI:1.01-1.114, p=0.010). (Table 2: Factors affecting the success of PFN).

DISCUSSION

The results of this study demonstrated that the radiological parameters of femur neck-shaft angle and tip-apex distance (TAD) directly affect the success of PFN in patients treated surgically with proximal femoral nail (PFN) for femur intertrochanteric fractures.

It has been reported in the literature that the effect on the success of PFN treatment of the femur neck-shaft angle, especially angles >130°, is that it leads to stress concentration by reducing the weight-bearing capacity of the implant (12-14). The significantly greater femur neck-shaft angle (p=0.037) of the unsuccessful patient group in the current study was found to be consistent with the literature. Kim JT et al. (15) reported that an angle in the range of 125°-130° was the most stable biomechanically in cases applied with PFN. Similarly, there are studies in the literature showing that the majority of unsuccessful cases have implants with varus placement (16, 17).

A TAD value >25mm has been reported in the literature to severely increase the risk of cut-out. Nikoloski et al. (18), showed that TAD <20mm could increase the risk of medial perforation, and therefore recommended that keeping TAD >20mm could be safer. In the current study, the TAD value was found to be significantly higher (p=0.045) in the patient group that resulted in failure, but no statistical significance as an independent risk factor was seen in the regression analysis, so these findings were consistent with the literature.

Complex fracture types (eg. intra-articular or multi-fragmented fractures) generally require more care and surgical experience. Achieving anatomic reduction and stable fixation of these types of fractures can be difficult and this can present challenges for the surgeon (19). In the growing geriatric patient population with increased average life expectancy, there is increased ICU admission during and after hip fracture treatment and as there is greater pain in these patients and this has been found to be associated with failure, the effect of systemic factors on surgical outcomes is seen once again (20, 21). In the current study, as trauma in the fracture etiology was only present in the unsuccessful group (p=0.015) these types of fractures were considered to have increased the surgical difficulties because of the more complex structure.

Although no direct statistically significant difference was observed between the successful results and the AO classification in this study, it was noteworthy that the angle values were higher in the A1 fractures in the unsuccessful group. This indicates that even fractures described as "simple" require more careful stabilisation (22-23).

Even if external factors are minimised in surgeries performed in the same centre with a similar technique, technical details such as implant selection and screw configuration can play an important role in failure. There are single helical blades or double screws according to the implant used in PFN treatment. The rotational stability provided by two screws can be obtained with a single helical blade (23, 24). The higher TAD values in patients applied with surgical treatment using double screws demonstrate that incorrect screw placement increases the risk of complications (4, 5).

An AUC value of 1 in ROC analysis indicates an excellent diagnostic test, whereas if this value is 0.5, it is coincidental, meaning there is no diagnostic value. In the ROC analysis of the current study, the AUC values were 0.635 for femur neck-shaft angle and 0.629 for TAD. These values show that although these parameters were of borderline diagnostic value they should be taken into consideration in the clinical decision-making process (25).

As seen from the results of this study, it is not possible to explain the failure of PFN with a single parameter. Factors such as age, systemic diseases, etiology, implant placement, surgeon's experience, and patient compliance should be evaluated together.

When the reduction quality was interpreted in light of the Chang reduction criteria in the failure group, most cases were found to be consistent with inadequate reduction quality, supporting the prognostic value of these criteria. However, some discrepancies were observed, as mechanical failure also occurred in certain patients who showed relatively acceptable reduction according to Chang criteria but had unfavorable radiological parameters such as increased tip–apex distance or non-optimal femoral neck–shaft angles. This finding indicates that Chang criteria and detailed radiological measurements should be interpreted together rather than independently when predicting mechanical failure after PFN fixation.

The retrospective design of this study, the relatively low number of patients and that it was conducted in a single centre can be evaluated as limitations of the study.

Clinical implications

The findings of this study have important implications for daily clinical practice. Maintaining the femoral neck–shaft angle within the optimal range and keeping the tip–apex distance below critical threshold values during PFN fixation may significantly reduce the risk of mechanical failure in elderly patients with intertrochanteric fractures. These results emphasize the importance of careful intraoperative reduction quality and precise implant positioning. Moreover, the radiological parameters identified in this study may assist surgeons in early identification of high-risk patients, enabling closer postoperative monitoring and timely intervention when necessary. Ultimately, these findings may contribute to improved functional outcomes, reduced revision surgery rates, and lower morbidity in the geriatric population.

Limitations and strengths

This study has several limitations that should be acknowledged. First, its retrospective design limits the ability to establish causal relationships. Second, the relatively small sample size and the single-center nature of the study may restrict the generalizability of the findings. In addition, although the follow-up period was adequate for evaluating mechanical failure, longer-term outcomes could not be fully assessed. Furthermore, potential confounding factors such as variations in bone quality, comorbidities, and surgeon-related technical differences could not be completely controlled.

Despite these limitations, this study also has important strengths. It provides real-world clinical data from a geriatric population, includes a clearly defined radiological assessment protocol, and offers a comprehensive evaluation of key mechanical risk factors such as femoral neck–shaft angle and tip–apex distance. Moreover, the relatively long follow-up period and the inclusion of detailed radiological measurements strengthen the reliability of the findings and contribute valuable evidence to the existing literature.

Future research in this field should focus on multicenter, prospective studies with larger sample sizes to validate the findings of the present study. Long-term follow-up studies are needed to better evaluate implant survival, functional outcomes, and revision rates. In addition, future studies should investigate the combined effects of bone quality, comorbidities, fracture patterns, and surgical technique on mechanical failure. Advanced imaging methods and computer-assisted surgical planning may also provide more precise evaluation of implant positioning and reduction quality in future clinical practice.

CONCLUSION

The results of this study showed that there was a significant relationship between the main causes of mechanical failure encountered in PFN treatment of inertrochanteric femur fractures and the radiological parameters such as implant angle and TAD. Especially the preservation of the neck-shaft angle at around 125° in implant fixation plays an important role in reducing the risk of cut-out. Similarly, a TAD value <25mm increases implant stability and reduces failure rates. However, neither of these parameters is sufficiently determinative alone, and the clinical outcomes can be optimised only with multifactorial evaluations.

Informed consent: Informed consent was obtained from all individual participants included in the study.

Conflict of Interests: The authors have no conflict of interests related to this article.

Funding sources: The authors declare that this study has received no financial support.

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