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Risk factors of excessive sliding in elderly patients with intertrochanteric fractures treated with PFNA-II: a retrospective observational study

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Abstract

Purpose Excessive sliding of cephalic components of cephalomedullary nails has been established to be significantly associated with the development of mechanical failures and unfavorable results in the surgical treatment of intertrochanteric fractures. This study aims to elucidate the risk factors that contribute to excessive sliding in elderly patients treated with PFNA-II devices for the fixation of intertrochanteric fracture.

Methods We conducted a retrospective analysis of patients aged 65 and older who presented with intertrochanteric fractures and underwent surgical treatment using PFNA-II devices at a university teaching hospital between January 2020 and December 2021. All patients were subjected to a minimum of one year of follow-up. We collected data on patient demographics, as well as preoperative, perioperative, and postoperative radiographic information, identifying mechanical failures during routine follow-ups. Patients were categorized into an excessive sliding group and a normal sliding group based on the sliding distance, with the optimal cut-off determined by receiver operating characteristic (ROC) curve analysis. Binary logistic regression was employed to identify independent risk factors associated with excessive sliding.

Result Among the 507 eligible patients, the mean postoperative sliding distance was 4.45 mm (SD, 5.39 mm; range, 0–31.67 mm). The cut-off for excessive sliding was determined as 6.75 mm, with 61 patients (12.0%) classified as hving excessive sliding, of whom 18 (29.5%) experienced mechanical failures. Binary logistic analysis indicated that poor reduction quality (OR = 11.493, 95% CI: 3.386–39.014, $P < 0.001$), and Subtype P in LAT reduction (OR = 15.621, 95% CI: 5.984–40.779, $P < 0.001$) were independently associated with excessive sliding distance. Their associations were robust across subgroup analyses.

Conclusions Poor reduction quality and the Subtype P in LAT reduction were identified as independent risk factors for excessive sliding. It is essential for surgeons to be mindful of these two risk factors during preoperative assessment and intraoperative procedures.

Keywords Intertrochanteric fractures, Sliding distance, Implant fixations, Postoperative mechanical failures

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Introduction

Intertrochanteric fractures constitute approximately 50% of all hip fractures, significantly impacting hip function and overall quality of life, with a reported one-year mortality rate ranging from 11 to 27% [1, 2]. Current management strategies predominantly involve the use of sliding hip screws or intramedullary nails equipped with sliding screws or helical blades [3–6]. During the postoperative weight-bearing phase, the proximal fragment glides along the helical blade while the distal fragment engages directly, thereby enhancing stability and promoting healing at the fracture site [7]. However, the excessive increase in the sliding distance clearly increases the risk of mechanical failures, i.e. nail breakage and cut-out by seven fold, and leads to reduced hip function and loss of independence in walking [7–9]. Consequently, identifying pertinent risk factors influencing the sliding distance is crucial for mitigating these potentially catastrophic mechanical failures.

Several studies have endeavored to elucidate the risk factors correlated with excessive sliding distance. In 2014, Liu et al. [10] conducted a retrospective analysis of 223 patients treated with a tapered femoral nail (TFN) and identified calcar reduction and fracture stability as independent risk factors for excessive sliding (defined as exceeding 10 mm). In 2021, Kenta et al. [11] performed a retrospective study involving 115 patients followed for six months, concluding that female gender, unstable fracture type, increased tip-apex distance (TAD), and suboptimal reduction in one plane were associated with excessive postoperative sliding (exceeding 8 mm). More recently, Li et al.'s retrospective case–control study of 369 patients treated with PFNA-II and followed up for six months, suggesting that low medullary filling and a negative fracture reduction pattern in lateral radiographs were independent risk factors for excessive sliding (exceeding 10 mm) [12]. Nonetheless, these investigations may be constrained by limitations such as small sample sizes, inadequate adjustment for covariates or confounders, arbitrary thresholds for defining excessive sliding distance, and relatively short follow-up durations. We hypothesize that there are other factors from bone mass or quality and reduction quality that will influence the development of excessive sliding.

The aim of this study was to characterize the sliding distance associated with intertrochanteric fractures treated with the PFNA-II and to identify the thresholds and independent risk factors contributing to excessive sliding.

Materials and methods

This study received approval from the Ethics Committee and adhered to the international ethical guidelines outlined in the Declaration of Helsinki for research involving human subjects. All participants provided written informed consent.

Data source and study population

We conducted a retrospective study involving patients with intertrochanteric fractures (ITF) at our tertiary care referral hospital from January 2021 to December 2022.

Inclusion criteria are as follows: (1) intertrochanteric fracture, (2) surgery performed within two weeks of the fracture, and (3) closed reduction internal fixation surgery. Exclusion criteria are as follows: (1) age < 65 years, (2) high-energy trauma fractures, (3) comorbid primary tumors, (4) multiple or open fractures, (5) pathological fractures, (6) previous fracture in the same femur, and (7) incomplete follow-up data.

The treatments used the Proximal Femoral Nail Antirotation II device (PFNA II) (Synthes GmbH, Oberdorf, Switzerland). Patient data, including age, sex, body mass index (BMI), side of injury, American Society of Anesthesiologists (ASA) score, and intramedullary nail lengths, were extracted from the hospital database. Radiographic evaluations used a picture archiving and communication system (PACS) for immediate preoperative and postoperative evaluations, including anteroposterior projections of the pelvis and affected hip joints in axial projection, as well as anteroposterior and lateral radiographs. Follow-up evaluations were conducted at one, three, six, nine, and twelve months post-discharge, with radiographs taken at each visit for comparison. Postoperative complications and sliding distances were assessed through clinical evaluations and radiographic imaging during follow-up visits. Two independent trauma orthopedic specialists reviewed all hip radiographs (anteroposterior and lateral views) retrieved from the medical record system. Measurements of sliding distance and complication (e.g., cut-out, implant failure) were performed using standardized protocols. Discrepancies between reviewers were resolved through consensus discussions, with adjudication by a senior radiologist if required. Measurements of the tip-apex distance (TAD) and calcar-referenced tip-apex distance (Cal-TAD) were taken from postoperative photographs. Radiological evaluations included preoperative considerations such as fracture classification (AO / OTA 2007), stability, and the presence of a combined posterolateral wall fracture. Postoperative evaluations focused on TAD, Cal-TAD, Parker ratio, distal locking mode, Cleveland-Bosworth quadrant, reduction quality, and classification of reduction in AP and LAT view.

The postoperatively mechanical failures at one year were included as follows: (1) cut-out, breakage, and lateral displacement of the helical blade or distal locking nail, (2) periprosthetic fracture, (3) malunion, delayed union, nonunion, (4) hip varus deformity (assessed by the neck-shaft angle variation). All these findings could be identified on orthopantomograms during the follow-up review [13].

Definition and measurements of parameters

The TAD defined by Baumgaertner is the sum of the distances from the tip of the screw to the apex of the femoral head in anteroposterior and lateral views [14]. Cal-TAD defined by Kuzyk, is the sum of the distances from the tip of the helical blade to the intersection of the femoral head and the medial femoral neck cortical tangent on the AP view and from the tip of the helical blade to the apex of the femoral head on the Lat view [15]. Parker's ratio is defined as the distance from the helical blade to the inferior and posterior margins of the femoral neck in the AP or Lat views [16]. According to Cleveland's initial report, the femoral head is divided into nine zones on postoperative frontal and lateral views [17]. The quality of reduction (poor, acceptable, good) is based on postoperative radiographic evaluation according to Baumgaertner's criteria [14]. Fracture gapping was measured according to the method described by Ciufor et al., with the measured distance corrected using the known diameter of the lag screw [18]. Extramedullary fractures had the inner cortex of the proximal bone fragment outside the medial cortex of the distal fragment. Anatomical fractures had continuous medial cortices of the proximal and distal fragments. Intramedullary fractures had the medial cortex of the proximal fragment inside the distal fragment. Using a lateral view, reductions were classified as subtype A, N, or P. Subtype A had the anterior anterior cortex of the proximal fragment and on top of the anterior cortex of the distal fragment. Subtype N had continuous anterior cortices of the proximal and distal fragments. Subtype P had the anterior cortex of the proximal fragment that entered the medullary cavity of the distal fragment [19, 20].

The sliding distance of the helical blade was determined from the AP view taken immediately after surgery and at the final follow-up. Measurements were performed by senior physicians. The length of the lag screw (AB) and the distance (AC) from the tip of the lag screw (A) to the intersection point (C) of lines drawn between the lag screw axis and the contact point with the external sides of the nails and screws were measured at 2 weeks, 4 weeks, 3 months and 6 months postoperatively. Each measurement at the final follow-up was defined as AC' or AB', and the sliding distance between the nail and the lag screw was calculated as AC – AC' (AB/AB') (standardized for magnification) (Fig. 1).

Surgical procedure

All operations were carried out by a group of four hip surgeons, each with more than five years of surgical expertise. Operations occurred on a radiolucent fracture table, managed by a senior chief surgeon with professional training, under the direction of general anesthesia and fluoroscopy. The surgeries were performed within 2–6 days of patient admission, using general and spinal anesthesia. No intraoperative complications were encountered.

Postoperative management

Each patient was given antithrombotic prophylaxis using low molecular weight heparin (enoxaparin) and antibiotic prophylaxis with a second-generation cephalosporin (cefazolin). All individuals followed a standardized rehabilitation protocol. Postoperative functional exercises were strongly recommended. On the first day, isometric quadriceps and ankle pump exercises were initiated, followed by

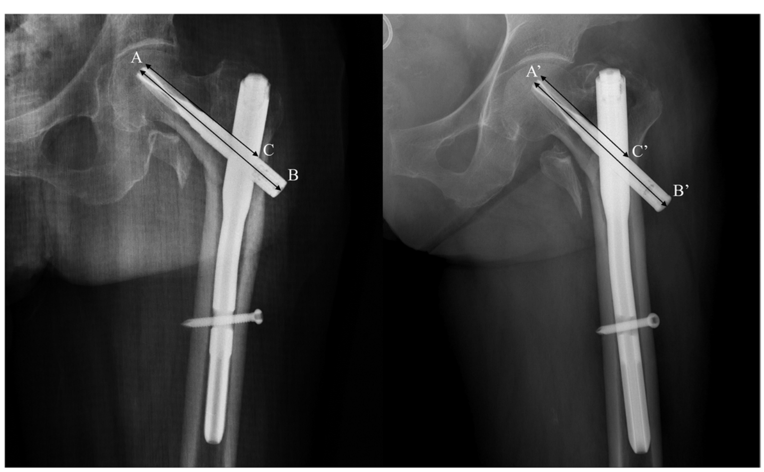

Fig. 1 Measurement protocol The sliding distance = AC—AC'(AB/AB')

weight-bearing as tolerated starting 4 weeks after surgery. Full weight bearing was limited until bone union, typically 3–5 months. At each follow-up appointment, ortho- and lateral X-rays were taken to monitor healing progress. Internal criteria to assess fracture healing included the absence of localized pain and abnormal activity, radiographs showing a blurred fracture line, and continuous trabeculae.

Statistical analysis

We performed the Kolmogorov–Smirnov test to assess the normality of continuous variables, which were expressed as the mean ± standard deviation for variables that followed a normal distribution and analysed using Student's t test, or as the median and interquartile range, and the analysis was performed by performing the Mann–Whitney test. Categorical variables were expressed as numbers and percentages and analyzed using the Pearson chi-square test.

Patients were divided into two groups based on the presence or absence of failures: the 'non-failure group' and the 'failure group'. The multifactorial generalized additive model (GAM) was used to assess the relationship between sliding distance and the probability of postoperative mechanical failures. The model was based on the penalized spline method and adjusted for all covariates. The receiver operating characteristic (ROC) curve was also used to determine the optimal cut-off value of sliding distance, and patients were divided into two groups based on this value: the 'excessive sliding group' (equal to or exceeding the cut-off value) and the 'normal sliding group'. A binary logistic regression model was used to assess independent risk factors associated with over-sliding. Pre-specified subgroup analyses were then conducted for age, gender, BMI, and fracture type to investigate population heterogeneity. A P-value < 0.05 was considered statistically significant, and all tests were two-sided. SPSS version 26.0 (IBM Corp, Armonk, NY, USA) and R software (R Foundation for Statistical Computing version 3.6.5) were used for data analysis.

Result

A total of 507 patients with intertrochanteric fractures were included in this retrospective study. The mean age was 77.60 ± 7.59 years. 208 patients were male and 299 patients were female. According to the AO/OTA classification system, 277 fractures were considered stable and 230 fractures were considered unstable. Long nails were used in 120 patients and short nails in 387 patients. The mean follow-up time was 13.4 months (12–56 months). The mean TAD was 22.79 mm (SD, 7.78MM; median: 21.63 mm; range: 2.22–47.22 mm). Postoperative mechanical failures occurred in 33 (6.5%) patients included. The mean sliding distance was 4.45 mm (SD, 5.39 mm; range: 0–31.67 mm).

In comparing the failure group with the non-failure group, differences reached or approached statistical significance in terms of BMI (P = 0.045), integrity of lateral femoral wall (P = 0.038), AP Blade position (P = 0.034), reduction quality (P < 0.001), distal locking mode (P = 0.006), fracture classification (P = 0.091), lateral reduction mode (P < 0.001) and sliding distance (P < 0.001) (Table 1), we included all covariates in the GAM curve for adjustment.

The adjusted GAM curve shows that when the sliding distance exceeds 4.4 mm, the risk of postoperative mechanical failures is considerably elevated with an almost linear relationship (Fig. 2). According to the analysis of the critical value of the ROC curve for postoperative mechanical failures, the optimal cut-off value for the sliding distance was 6.75 mm, in order to balance sensitivity and specificity. Combining the cut-off points obtained from the GAM and the ROC curve, and considering their clinical significance, we divided the patients into excessive sliding and normal sliding groups using the cut-off point obtained from the ROC curve (Fig. 3). Significant differences were observed between the excessive sliding and normal sliding groups regarding reduction quality and lateral reduction mode (Table 2). Binomial logistic regression analysis showed that poor reduction quality (OR = 11.493, 95% CI: 3.386–39.014, P < 0.001) and the Subgroup P in LAT reduction were independent risk factors for excessive sliding in elderly patients with intertrochanteric fractures (Table 3). The H–L test showed that the final model had good applicability (X^2 = 1.806, P = 0.781). To illustrate the findings visually, Fig. 4 presents a representative case of excessive sliding, reduction quality and Subtype P in LAT reduction. The immediate postoperative and follow-up X-ray images clearly show the progression of sliding distance.

Subgroup analyses were performed using factors known to be potentially associated with an increased risk of excessive sliding, namely age, gender, TAD, and fracture stability. Compared to the lateral reduction subgroup N, the risk of excessive sliding was significantly higher in the subgroup younger (65–75 years) (P for interaction value = 0.003), the subgroup of female (P for interaction value = 0.001), the subgroup with a TAD > 25 mm (P for interaction value = 0.001), and the subgroup of unstable fracture (P for interaction value = 0.004), while no statistical differences were found in these subgroups for patients with poor reduction quality (Table 4).

Discussion

This retrospective study specifically targeted elderly patients with intertrochanteric fractures. The results showed that poor reduction quality and the Subtype P in LAT reduction were independent risk factors for

Table 1 Univariate analysis of variables with interest between normal-sliding group and excessive sliding group

	Non-failure group (*n* = 474)	Failure group (*n* = 33)	P
AGE (years)	77.66 ± 7.67	76.70 ± 6.39	0.481
SEX, n (%)			1.000
Male	206 (43.5%)	14 (42.4%)	
Female	268 (56.5%)	19 (57.6%)	
BMI (Kg/m2)	24.46 ± 3.78	25.81 ± 2.58	**0.045**
ASA score, n (%)			0.590
I-II	256 (54.0%)	16 (48.5%)	
III-IV	218 (46.0%)	17 (51.5%)	
Lateral, n (%)			0.367
Left	260 (54.9%)	15 (45.5%)	
Right	214 (45.1%)	18 (54.5%)	
Fracture Type, n (%)			0.284
Stable	262 (55.3%)	15 (45.5%)	
Unstable	212 (44.7%)	18 (54.5%)	
TAD (mm)	22.71 ± 7.75	23.77 ± 8.32	0.451
Cal-TAD (mm)	24.96 ± 6.96	25.00 ± 6.32	0.973
AP parker (%)	39.72 ± 9.05	41.60 ± 10.76	0.255
LAT parker (%)	54.46 ± 11.42	54.12 ± 12.63	0.870
Blade position, n (%)			
AP			**0.034**
Central	260 (54.9%)	14 (42.4%)	
Superior	44 (9.3%)	8 (24.2%)	
Inferior	170 (35.9%)	11 (33.3%)	
LAT			0.493
Central	280 (59.1%)	22 (66.7%)	
Anterior	149 (31.4%)	10 (30.3%)	
Posterior	45 (9.5%)	1 (3.0%)	
Nail length, n (%)			0.203
Short	365 (77.0%)	22 (66.7%)	
Long	109 (23.0%)	11 (33.3%)	
Lateral femoral wall, n (%)			**0.038**
Intact	389 (82.1%)	22 (66.7%)	
Fracture	85 (17.9%)	11 (33.3%)	
Reduction, n (%)			**< 0.001***
Good	344 (72.6%)	118 (54.5%)	
Acceptable	123 (255.9%)	9 (27.3%)	
Poor	7 (1.55%)	6 (18.2%)	
Classification, n (%)			0.091
31A1	101 (21.3%)	5 (15.2%)	
31A2	288 (60.8%)	17 (51.5%)	
31A3	85 (17.9%)	11 (33.3%)	
Distal locking mode, n (%)			**0.006**
Static locking	275 (58.0%)	11 (33.3%)	
Dynamic locking	199 (42.0%)	22 (66.7%)	
AP reduction, n (%)			0.420
Intramedullary type	45 (9.5%)	5(15.2%)	
Anatomical type	277 (58.4%)	20 (60.6%)	
Extramedullary type	152 (32.1%)	8 (24.2%)	

Table 1 (continued)

	Non-failure group (*n* = 474)	Failure group (*n* = 33)	P
LAT reduction, n (%)			**< 0.001***
Subtype A	109 (23.0%)	2 (6.1%)	
Subtype N	350 (73.8%)	23 (69.7%)	
Subtype P	15 (3.2%)	8 (24.2%)	
Sliding distance (mm)	2.25 (0.99, 4.32)	7.02 (7.31, 13.74)	**< 0.001***

Abbreviations: *BMI* Body mass index, *ASA* American Society of Anesthesiologists, *TAD* tip-apex distance, *Cal-TAD* calcar-referenced tip-apex distance, *AP* anterior, *LAT* lateral

* $P < 0.05$ was considered statistically significant

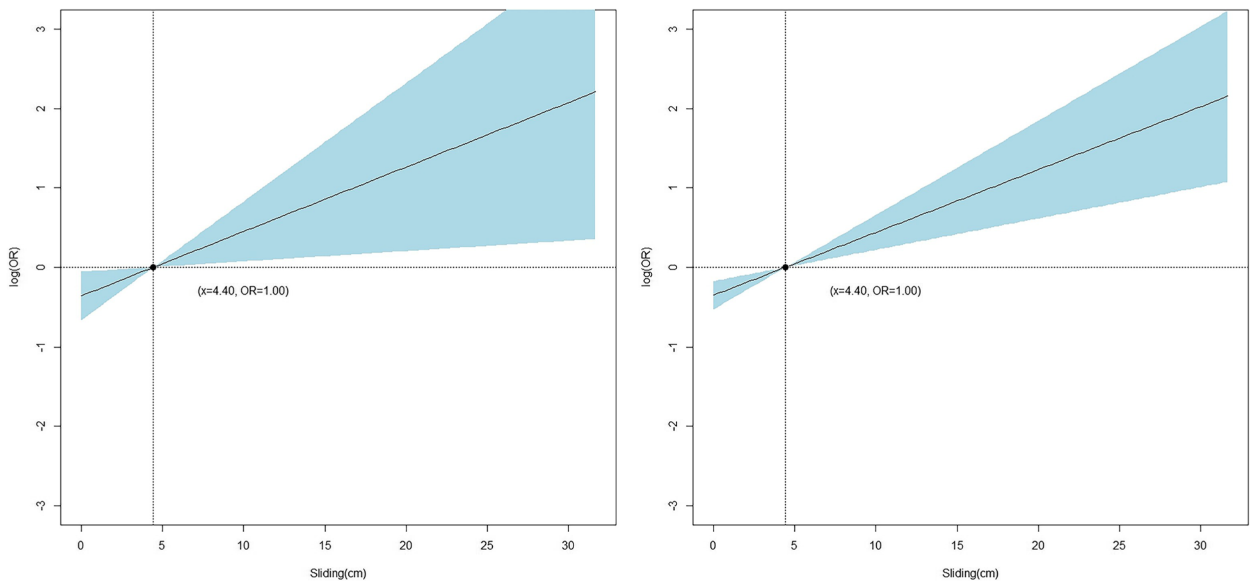

Fig. 2 Visualization of the adjusted risk for postoperative mechanical failures according to sliding distance based on the generalized additive model

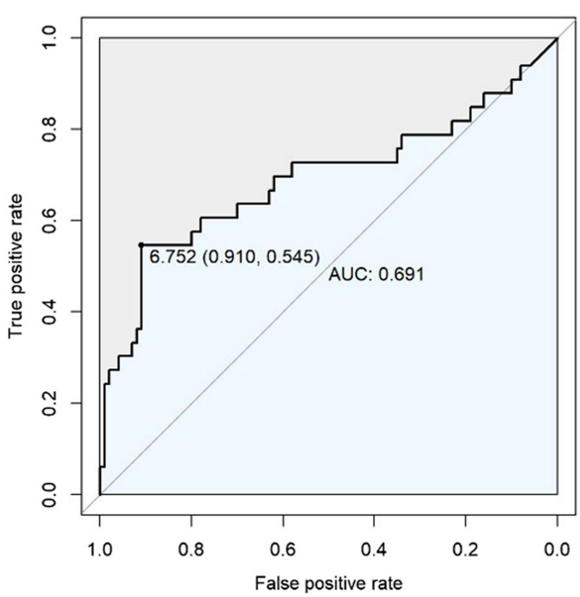

Fig. 3 The receiver operating characteristic curve (ROC) of the logistic regression

excessive sliding. In addition, subgroup analysis showed statistically significant heterogeneity in the subgroups of age, gender, TAD, and fracture stability. These findings emphasize the importance of optimizing reduction and a more refined treatment strategy in elderly patients with intertrochanteric fractures.

The quality of reduction, assessed by fracture gap and angulation, has long been recognized as a critical determinant of prognosis in intertrochanteric fractures [21, 22]. When a large fracture gap is present and stable bone contact is lacking, the iliopsoas and adductor muscles exert substantial traction and internal rotation forces on the distal fragment [23]. To achieve secondary stability under these circumstances, the helical blade must slide farther, and all forces are transmitted through the implant's main nail rather than through the bone. Ultimately, this leads to a conflict between bone integration and mechanical loading [24]. As the femoral anteversion and neck-shaft angles increase, the weight-bearing line becomes more eccentric, transverse shear forces

Table 2 Univariate analysis of variables with interest between normal-sliding group and excessive sliding group

	Normal-sliding group (*n* = 446)	**Excessive sliding group (*n* = 61)**	**P**
AGE (years)	77.61 ± 7.60	77.49 ± 7.64	0.908
SEX, n (%)			0.583
Male	185 (41.5%)	23 (37.7%)	
Female	261 (58.5%)	38 (62.3%)	
BMI (Kg/m2)	24.48 ± 3.77	25.05 ± 2.38	0.266
ASA score, n (%)			0.473
I-II	236 (52.9%)	36 (59.0%)	
III-IV	210 (47.1%)	25 (41.0%)	
Lateral, n (%)			0.173
Left	247 (55.4%)	28 (45.9%)	
Right	199 (44.6%)	33 (54.1%)	
Fracture Type, n (%)			0.683
Stable	242 (54.3%)	35 (57.4%)	
Unstable	204 (45.7%)	26 (42.6%)	
TAD (mm)	22.74 ± 7.81	23.07 ± 7.66	0.761
Cal-TAD (mm)	24.99 ± 7.07	24.80 ± 5.72	0.836
AP parker (%)	39.94 ± 9.26	39.12 ± 8.48	0.517
LAT parker (%)	54.67 ± 11.54	52.76 ± 10.99	0.222
Blade position, n (%)			
AP			0.608
Central	240 (53.8%)	34 (55.7%)	
Superior	48 (10.8%)	4 (6.6%)	
Inferior	158 (35.4%)	23 (37.7%)	
LAT			0.935
Central	265 (59.4%)	37 (60.7%)	
Anterior	141 (31.6%)	18 (29.5%)	
Posterior	40 (9.0%)	6 (9.8%)	
Nail length, n (%)			0.423
Short	343 (76.9%)	44 (72.1%)	
Long	103 (23.1%)	17 (27.9%)	
Lateral femoral wall, n (%)			0.191
Intact	360 (80.7%)	51 (83.6%)	
Fracture	86 (19.3%)	10 (16.4%)	
Reduction, n (%)			**< 0.001***
Good	319 (71.5%)	43 (70.5%)	
Acceptable	122 (27.4%)	10 (16.4%)	
Poor	5 (1.1%)	8 (13.1%)	
Classification, n (%)			0.660
31A1	95 (21.3%)	11 (18.0%)	
31A2	265 (59.4%)	40 (65.6%)	
31A3	86 (19.3%)	10 (16.4%)	
Distal locking mode, n (%)			0.271
Static locking	256 (57.4%)	30 (49.2%)	
Dynamic locking	190 (42.6%)	31 (50.8%)	
AP reduction, n (%)			0.581
Intramedullary type	42 (9.4%)	8(13.1%)	
Anatomical type	261 (58.5%)	36 (59.0%)	
Extramedullary type	143 (32.1%)	17 (27.9%)	
LAT reduction, n (%)			**< 0.001***
Subtype A	102 (22.9%)	9 (14.8%)	
Subtype N	335 (75.1%)	38 (62.3%)	
Subtype P	9 (2.0%)	14 (22.9%)	

Abbreviations: *BMI* Body mass index, *ASA* American Society of Anesthesiologists, *TAD* tip-apex distance, *Cal-TAD* calcar-referenced tip-apex distance, *AP* anterior, *LAT* lateral

* $P < 0.05$ was considered statistically significant

Table 3 The logistic regression analysis on the risk factors of excessive sliding

Variables	**Odds ratio**	**95%CI**	***P* value**
Reduction			
Good	1 (ref.)	1 (ref.)	
Acceptable	0.495	0.224 – 1.094	0.082
Poor	11.493	3.386 – 39.014	< 0.001*
LAT reduction			
Subgroup N	1 (ref.)	1 (ref.)	
Subgroup A	0.811	0.366 – 1.795	0.606
Subgroup P	15.621	5.984—40.779	< 0.001*

Abbreviation: *LAT* lateral

* $P < 0.05$ was considered statistically significant

rise, and longitudinal axial compression decreases. These changes weaken the hip adductor muscles' lever arm and alter their length-tension relationship [13]. Under gravitational load, the femoral head-neck fragment may be more inclined to subside posteriorly. Furthermore, stress concentration at the junction of the spiral blade and main nail intensifies, diminishing overall implant stability and increasing the sliding distance. In our study, patients with poor reduction had a mean sliding distance of 9.44 mm, which was significantly greater than those with good (2.62 mm) or acceptable (2.25 mm) reductions. The risk of excessive sliding was 11.493 times higher in the poor reduction group than in the good reduction group. These findings are consistent with a single-center retrospective study by Liu et al. involving 223 patients, which showed that patients with poor reduction had an average sliding distance of 7.6 mm, and reduction quality was an independent risk factor for excessive sliding [10]. In addition, a retrospective cohort study by Yoon including 106

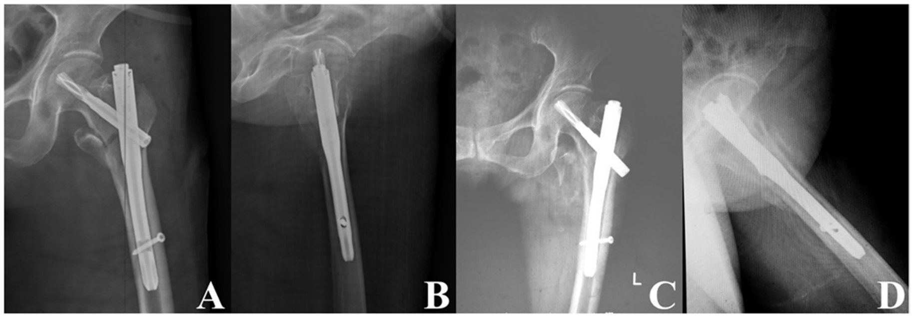

Fig. 4 Immediate postoperative (**A** AP view, **B** LAT view) and follow-up (**C** AP view, **D** LAT view) X-ray images of a representative patient with excessive sliding. Poor reduction quality and Subtype P in LAT reduction are evident, with significant sliding distance progression observed during follow-up

Table 4 Hazard ratio and 95% confidence intervals of incident failure in subgroups

	Subgroup	HR(95%CI)			P
		Good group	Acceptable group	Poor group	
Age	65–75	1(ref.)	0.702 (0.211–2.341)	15.726 (0.807–306.582)	0.242
	≥76	1(ref.)	0.303 (0.087–1.055)	10.628 (2.735–41.309)	
Sex	male	1(ref.)	0.515 (0.154–1.724)	6.258 (1.047–37.404)	0.416
	female	1(ref.)	0.499 (0.169–1.472)	20.302 (3.490–118.103)	
TAD	≤25	1(ref.)	0.717 (0.285–1.806)	10.205 (2.483–41.941)	0.685
	>25	1(ref.)	0.209 (0.039–1.121)	29.953 (1.583–425.588)	
Fracture	stable	1(ref.)	0.592 (0.223–1.570)	24.245 (2.415–243.382)	0.541
	unstable	1(ref.)	0.352 (0.085–1.465)	9.410 (1.900–46.595)	
	Subgroup	**HR(95%CI)**			**P**
		Subgroup N	**Subgroup A**	**Subgroup P**	
Age	65–75	1(ref.)	0.329 (0.066–1.644)	42.649 (7.762–234.328)	**0.003***
	≥76	1(ref.)	1.294 (0.504–3.323)	6.675 (1.816–25.197)	
Sex	male	1(ref.)	0.411 (0.089–1.911)	7.942 (2.174–29.016)	**0.001***
	female	1(ref.)	1.178 (0.443–3.129)	33.627 (7.530–150.175)	
TAD	≤25	1(ref.)	1.126 (0.469–2.703)	15.731 (4.660–53.105)	**0.001***
	>25	1(ref.)	0.194 (0.018–2.104)	21.548 (3.662–126.796)	
Fracture	stable	1(ref.)	1.019 (0.399–2.600)	11.256 (3.111–40.730)	**0.004***
	unstable	1(ref.)	0.460 (0.093–2.277)	26.125 (5.629–121.250)	

* $P<0.05$ was considered statistically significant

patients reported that the unacceptable reduction group had more than twice the sliding distance compared with the good and acceptable groups [9]. Ensuring a high-quality reduction of intertrochanteric fractures particularly maintaining a minimal fracture gap, and restoring a normal anteversion angle, and a neck-shaft angle is thus essential for implant stability and favorable postoperative outcomes.

Anteromedial cortical support reduction is considered a nonanatomic reduction that achieves structural structural support and represents the sole residual callus-bearing region transmitting load between the implant and the host bone. Debate over the continuity and optimal restoration of this support has intensified in recent years [25, 26]. Meanwhile, achieving an acceptable reduction mode remains challenging because of constraints imposed by the iliofemoral ligament, the wedging effect of the intramedullary nail, and gravitational forces during traction reduction [27, 28]. In our study, the mean sliding distance of Subtype P reached 12.17 mm, with the risk of excessive sliding being 15.621 times higher than that of Subtype N. In a retrospective cohort study involving 128 individuals, Tsukada et al. reported that the mean sliding distance of the P subtype with short intramedullary nails was 7.8 mm, significantly greater than that observed in the A (3.4 mm) and N (2.6 mm) subtypes [29]. Kozono et al.'s retrospective study included 136 patients reported that postoperative subtype N can lead to subtype P during the follow-up period when the contact of anterior fracture sites was not obtained [30]. We posit that femoral neck anteversion leads to posterior-to-anterior insertion of the spiral blade, causing the head-neck fragment to slide along the anterior–posterior axis. If the head-neck fragment is positioned posteriorly relative to the femoral fragment, the majority of impact force is directed toward the thin, fragile posterior cortex, resulting in fracture collapse and excessive sliding.

Significant heterogeneity and an increased HR for the development of excessive sliding were observed for the P subtype in the subgroup younger (65–75 years), female, TAD > 25 mm, and unstable fracture. Younger patients are encouraged to bear weight early due to better physiologic reserve, which contributes to functional recovery, and the higher level of activity results in greater stresses on the intramedullary nail during fracture healing [25, 31]. In female patients, bone loss is exacerbated by the decrease in estrogen levels after menopause, and the significant decrease in trabecular bone mass in particular decreases the mechanical support of the fracture area, further increasing the risk of intramedullary nail excessive sliding [32, 33]. When the TAD is too large, the helical blade is away from the femoral moment area with abundant trabeculae in the compression bone, and instead comes into contact with the more fragile peripheral cortical bone, resulting in uneven load distribution and more shear forces concentrated in the weak bone region [19]. As a result, the intramedullary nail is difficult to stabilize under rotational moments and axial loads, and the sliding distance is subsequently increased. In unstable intertrochanteric fractures, structural disruption of the anterior medial cortex prevents the formation of a mechanical conduction axis during weight bearing, and there are insufficient points of contact in the region of loading. Even after reduction, the anterior medial cortex is unable to effectively bear axial stresses, resulting in secondary rotational slippage of the fracture end during weight bearing [34]. Therefore, for the above subgroup of patients, especially those with poor anterior cortical alignment, it is recommended to delay full weight-bearing and use a walker-assisted gait training program during rehabilitation. In addition, strict radiographic follow-up with closed monitoring should be performed to assess fracture stability and dynamic changes in the fixation device to prevent excessive sliding and implant failure [35].

This study significantly improved the objectivity and clinical relevance of the study by including the largest sample size of patients to date and precisely defining the sliding distance thresholds in conjunction with GAM and ROC curves. Subtype P was also identified as an independent risk factor for excessive sliding distance and its impact was quantified, providing a new perspective for optimizing the quality of intraoperative repositioning. In addition, the subgroup analysis revealed the heterogeneous performance of specific high-risk populations, laying the foundation for personalized treatment strategies. However, the following limitations of this study should be noted, the first of which is that the article has the limitations of a retrospective study. Second, we focused solely on fracture healing outcomes and failures, neglecting the inclusion of clinical criteria or functional rating scales. This deliberate choice was made to evaluate the efficacy and reliability of internal fixation, prioritizing objective measures over subjective assessments. Third, this study did not consistently include bone density data and imaging of the contralateral hip joint, which restricted the ability to compare neck-shaft angles between the affected and healthy sides. As varus reduction may be associated with a higher failure rate, future studies should incorporate bone densitometry and ensure that comprehensive imaging protocols are used to facilitate such analyses and further validate these findings. Lastly, our statistical analysis relied on single-center data, the patient populations were all region-specific elderly intertrochanteric femur fracture populations, reflecting the specific demographic characteristics and healthcare setting of our institution, which may differ from other regions or healthcare systems. This could limit the generalizability of our findings to broader populations. Also, the study exclusively included patients treated with PFNA-II devices, which might not directly extrapolate to those managed with other fixation techniques or devices. To enhance the robustness of our findings, we recommend further validation and optimization through multicenter, large-sample randomized controlled trials with extended follow-up periods and a more comprehensive biomechanical analysis in future research.

Conclusion

In conclusion, our study found that poor reduction quality, and the Subtype P in LAT reduction were the independent risk factors for excessive sliding. It is essential for surgeons to be mindful of these two risk factors during preoperative assessment and intraoperative procedures. Addressing these factors effectively can significantly enhance surgical outcomes and reduce the incidence of postoperative failures related to sliding distance.

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Code availability
Not applicable.

Clinical trial number
Not applicable.

Authors' contributions
YBZ and DWW designed the study; SAZ, RW, and JQL searched for relevant studies and abstracted the data; HCG, CSL, TYW, and YJY analyzed and interpreted the data; SAZ wrote the manuscript; YBZ and DWW approved the final version of the manuscript. All authors reviewed the manuscript before submitting it.

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Data availability
The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Declarations

Ethics approval and consent to participate
This study was performed in line with the principles of the Declaration of Helsinki. Approval was granted by the local ethical committee (The 3rd Hospital of Hebei Medical University, Shijiazhuang, China; Ke2022-131-1). All subjects gave their written informed consent to take part in the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

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