The Research Journal of Medical Sciences
[E-ISSN: 3078-2481| P-ISSN: 3078-2473]
Available on: https://rjmsonline.com/
Volume: 08 | Issue: 01, 2026
DOI: 10.5281/zenodo.20522264

Research Article *Open Access*

Radiological Determinants of Fixation Success in Intertrochanteric Fractures Treated with PFN and PFN-A

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Source of support: Nil.
Conflict of interest: None

Received: 27-04-2026
Accepted: 12-05-2026
Available online: 03-06-2026

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Abstract

Background: Intertrochanteric fractures are a major cause of morbidity in the elderly, with cephalomedullary fixation widely accepted for unstable patterns. Proximal femoral nail (PFN) and proximal femoral nail anti-rotation (PFN-A) offer biomechanical advantages; however, comparative evidence from large Indian cohorts with extended follow-up remains limited.

Methodology: This retrospective observational study evaluated 286 skeletally mature patients with AO/OTA 31-A1 to A3 intertrochanteric fractures treated between 2022 and 2025 using closed reduction and internal fixation with PFN (n=162) or PFN-A (n=124). Postoperative radiological parameters including tip–apex distance (TAD), Cleveland index positioning, neck-shaft angle restoration and reduction quality were analysed. Fracture union was assessed up to two years. Statistical analysis was performed using SPSS version 22.

Results: Unstable fracture patterns constituted 79% of cases, and radiographic osteoporosis was present in 52%. Operative duration and haemoglobin drop were significantly lower in the PFN-A group ($p<0.001$). Radiological fixation quality was comparable between implants (mean TAD 22.1±4.2 mm; optimal Cleveland positioning 93%). Overall fracture union at two years was 97% (96% PFN vs 98% PFN-A; $p=0.99$). PFN-A demonstrated earlier radiological progression towards union and superior outcomes in osteoporotic patients ($p=0.04$). Complication rates were low and similar between groups. Logistic regression identified TAD >25 mm and negative reduction as independent predictors of fixation failure.

Conclusion: Both PFN and PFN-A provide reliable radiological and functional outcomes in intertrochanteric fractures. Fixation success is primarily influenced by reduction quality and optimal implant positioning rather than implant design alone, although PFN-A offers perioperative advantages and improved performance in osteoporotic bone.

Keywords: *Intertrochanteric Fractures; Femoral Fractures; Bone Nails; Fracture Fixation, Internal; Osteoporosis; Treatment Outcome.*

INTRODUCTION

Intertrochanteric fractures of the proximal femur constitute a significant cause of morbidity and mortality among elderly individuals, particularly in India, where increasing prevalence of osteoporosis and low-energy falls has led to a rising incidence accounting for more than 50% of all hip fractures.[1] Surgical fixation using cephalomedullary devices such as the proximal femoral nail (PFN) and proximal femoral nail anti-rotation (PFN-A) has become the preferred treatment modality for unstable fracture patterns owing to their superior biomechanical stability and minimally invasive application. Nevertheless, complications including screw cut-out, the Z-effect phenomenon and postoperative varus collapse continue to be reported in approximately 5% to 10% of cases, especially in patients with osteoporotic bone stock.[2]

Although both implants have demonstrated comparable functional outcomes, with mean Harris Hip Scores (HHS) approaching 80, PFN-A has been associated with potential advantages such as reduced operative time, decreased intraoperative blood loss and improved fixation in osteoporotic bone due to the enhanced anchorage provided by its helical blade design.[1,2] Radiological parameters including a tip–apex distance (TAD) of less than 25 mm, optimal lag screw or blade positioning within the centre–centre or centre-inferior zones of the Cleveland index and achievement of anatomical fracture reduction are recognized predictors of fracture union and implant survival. However, robust comparative evidence from larger Indian cohorts with extended follow-up remains limited.[1,3]

In this context, the present retrospective study evaluates a cohort of 286 patients with intertrochanteric fractures treated using PFN or PFN-A. The study aims to analyse postoperative radiological outcomes, fracture union rates up to two years and identify key predictors of successful fixation, with particular emphasis on intraoperative reduction quality and implant positioning parameters rather than preoperative imaging variables.

MATERIALS AND METHODS

This retrospective observational study evaluated 286 patients with intertrochanteric fractures managed between 2022 and 2025 using closed reduction and internal fixation with either a proximal femoral nail (PFN) or proximal femoral nail anti-rotation (PFN-A). Skeletally mature adults with AO/OTA type 31-A1 to A3 intertrochanteric fractures were included. Patients who were non-ambulatory prior to injury, had pre-existing hip osteoarthritis, sustained pathological fractures or had incomplete imaging records were excluded from the analysis. Fractures were classified according to the AO/OTA alphanumeric system based on postoperative anteroposterior (AP) pelvis and hip radiographs. Fracture stability was inferred from the quality of reduction and categorised as positive (anatomical restoration), neutral (partial cortical contact) or negative (varus collapse defined as $>10^0$ difference in neck–shaft angle compared with the contralateral side). Osteoporosis was assessed radiographically using Singh’s index (grades 1 to 6), based on trabecular pattern evaluation on AP radiographs.

Primary radiological parameters were measured on immediate postoperative AP and lateral radiographs using picture archiving and communication system (PACS) software (Figure – 1). These included tip–apex distance (TAD), defined as the sum of the distances from the tip of the screw or blade to the subchondral apex on AP and lateral views (target <25 mm); implant position according to the Cleveland index using a nine-zone grid on AP radiographs, with centre–centre or centre–inferior positions considered optimal; neck–shaft angle compared with the contralateral hip ($<5^0$ variance considered good, 5^0 to 10^0 acceptable, and $>10^0$ poor) and overall reduction type (Figure – 2). Fracture union was assessed at 6 weeks, 6 months and up to 2 years (where serial imaging was available) and was defined radiographically by the presence of bridging callus across at least three cortices on AP and lateral views. Secondary variables extracted from medical records included operative time (skin-to-skin duration in minutes), perioperative haemoglobin drop (percentage difference between pre- and postoperative values), implant length (short or long nail), patient demographics and duration of follow-up.

Statistical analysis was performed using SPSS software (version 22.0; IBM Corp., Armonk, NY, USA). Continuous variables were summarised as mean ± standard deviation or median with interquartile range according to data distribution, while categorical variables were expressed as frequencies and percentages. Normality of continuous variables was assessed using the Shapiro–Wilk test. Comparisons between PFN and PFN-A groups were performed using the independent samples t-test for normally distributed variables and the Mann–Whitney U test for non-parametric data. Categorical variables, including Cleveland index zones, reduction quality, Singh’s osteoporosis grades and fracture union rates were analysed using the Chi-square test or Fisher’s exact test as appropriate. Binary logistic regression analysis was undertaken to determine independent predictors of fixation failure or non-union, incorporating clinically relevant variables such as tip–apex distance (>25 mm), reduction quality, implant positioning, and osteoporosis grade. Results were reported as odds ratios with 95% confidence intervals. A p value <0.05 was considered statistically significant.

RESULTS

A total of 286 patients were included in the analysis, with a mean age of 68.4 years; 55% were male (Table – 1). PFN fixation was performed in 162 patients (short nail 58%, long nail 42%), while 124 patients underwent fixation with PFN-A (short nail 55%, long nail 45%). Unstable fracture patterns (AO/OTA 31-A2.2 to A3.3) accounted for 79% of cases. Radiographic osteoporosis (Singh’s index ≤3) was identified in 52% of patients (n = 149).

Operative duration was significantly shorter in the PFN-A group (36.7 ± 10.5 minutes) compared with the PFN group (47.3 ± 9.5 minutes; $p < 0.001$). Similarly, the mean perioperative haemoglobin drop was lower following PFN-A fixation (0.20%) than PFN fixation (0.42%; $p < 0.001$).

Postoperative radiological parameters were comparable between the two groups (Table – 2). The overall mean tip–apex distance (TAD) was 22.1 ± 4.2 mm, with no significant difference between PFN (22.5 mm) and PFN-A (21.8 mm; p =

0.32). Optimal implant positioning according to the Cleveland index was achieved in 93% of cases (92% PFN vs 95% PFN-A; p = 0.52). The mean postoperative neck–shaft angle was 130.2 ± 3.1^0, with no significant intergroup variation (p = 0.91). Positive reduction quality was achieved in 62% of patients overall (p = 0.48).

Fracture union at two-year follow-up was observed in 97% of patients (Figure – 3), with similar rates in the PFN (96%) and PFN-A (98%) groups (p = 0.99). Early radiological progression towards union at six weeks was more frequent in the PFN-A cohort (89%) compared with the PFN cohort (82%), although this difference did not reach statistical significance (p = 0.12). Overall complication rates were low and comparable between groups, occurring in 6.2% of PFN cases (n = 10), predominantly due to Z-effect phenomena and in 5.6% of PFN-A cases (n = 7), mainly related to implant-specific issues (p = 1.0). Functional outcomes were similar, with mean HHS of 79.3 ± 5.0 in the PFN group and 80.0 ± 4.6 in the PFN-A group (p = 0.24). It is depicted in Table – 3.

Subgroup analysis of osteoporotic patients (n = 149) demonstrated a significantly higher union rate in the PFN-A group (98%) compared with the PFN group (94%; p = 0.04). In this subgroup, optimal TAD and Cleveland positioning were associated with reduced risk of fixation failure (odds ratio 0.42 for non-union; p = 0.03). Multivariate logistic regression identified TAD greater than 25 mm (OR 3.2; p < 0.01) and negative reduction quality (OR 2.8; p = 0.02) as independent predictors of fixation failure (Figure – 4).

TABLES

Table – 1: Baseline demographic characteristics, fracture pattern distribution and radiographic osteoporosis profile of patients treated with PFN and PFN-A.

Demographics		**PFN**	**PFN-A**
Mean Age (y)		67.2±11.1	70.5±11.2
Gender	Male n (%)	79 (49%)	88 (71%)
	Female n (%)	83 (51%)	36 (29%)
AO Classification of fractures	AO 31-A1 n (%)	15	12
	AO 31-A2 n (%)	65	50
	AO 31-A3 n (%)	82	62
Singhs Index	≤3 n (%)	78 (48%)	71 (57%)
	>3 n (%)	84 (52%)	53 (43%)

Table – 2: Comparison of immediate postoperative radiological parameters, including tip–apex distance, neck–shaft angle restoration, implant positioning and reduction quality between PFN and PFN-A groups.

Post-Operative Radiological Parameters	**PFN**	**PFN-A**
TAD (mm, Mean±SD)	22.1±4.4	21.8±4.2
NSA (^{0} Mean±SD)	130.7±2.8	131.2±2.7
Optimal Cleveland n (%)	149 (92%)	118 (95%)
Positive Reduction n (%)	100 (62%)	78 (63%)

Table – 3: Clinical and radiological outcomes, including fracture union rates at serial follow-up, complication profile and functional outcomes (Harris Hip Score) in PFN and PFN-A groups.

Clinical Outcomes		**PFN**	**PFN-A**
Fracture Union	6 weeks n (%)	133 (82%)	110 (89%)
	6 months n (%)	152 (94%)	120 (97%)
	2 years n (%)	156 (96%)	122 (98%)
Complications n (%)		10 (6.2%)	7 (5.6%)
HHS (Mean±SD)		80.0±5.0	80.1±4.9

FIGURES

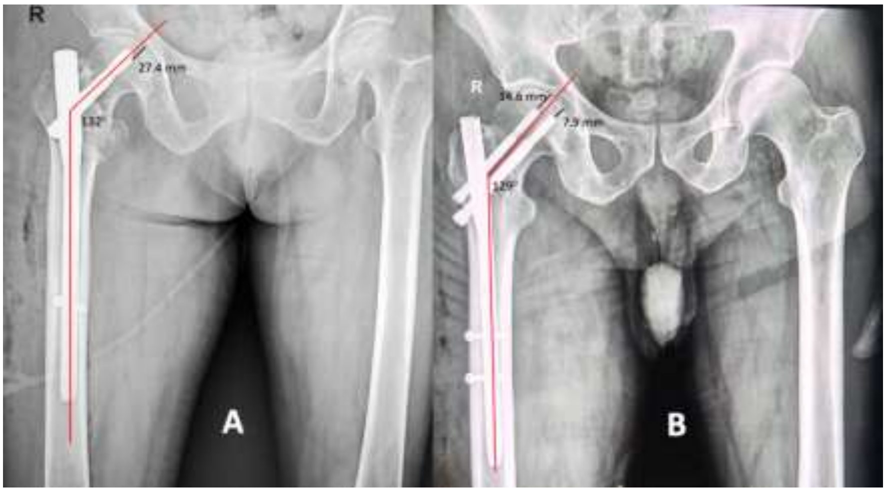

Figure – 1: Representative postoperative radiographs demonstrating fixation with proximal femoral nail (A) and proximal femoral nail anti-rotation (B), illustrating measurement of tip–apex distance (TAD) and restoration of the neck–shaft angle.

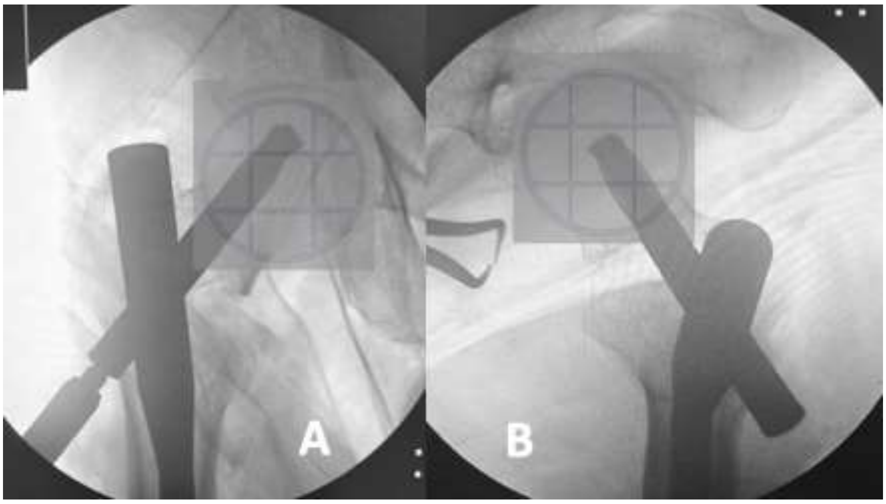

Figure – 2: Intra-operative fluoroscopic anteroposterior and lateral views demonstrating positioning of the cephalomedullary implant and lag screw within the femoral head, assessed using the Cleveland index grid.

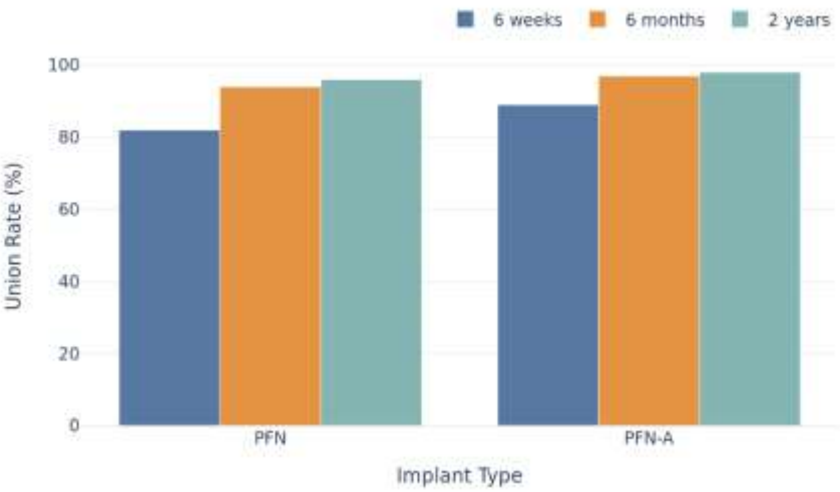

Figure – 3: Grouped bar chart comparing fracture union rates at 6 weeks, 6 months, and 2 years in PFN (n = 162) and PFN-A (n = 124) groups. PFN-A shows a trend toward earlier union, with comparable overall union at 2 years (97%; p = 0.99).

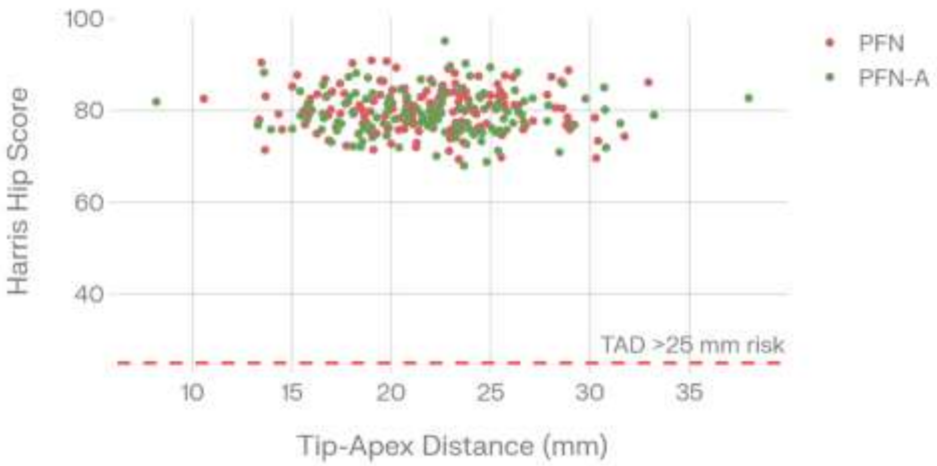

Figure – 4: Scatter plot showing the relationship between immediate postoperative tip–apex distance (TAD, mm) and Harris Hip Score (HHS) in PFN (red circles, n = 162) and PFN-A (green circles, n = 124) cases. The dashed line indicates the high-risk threshold (TAD > 25 mm). No significant correlation was observed (p = 0.24).

DISCUSSION

Intertrochanteric fractures predominantly affect the elderly population, with reported mean ages ranging from 68 to 70 years, which is consistent with the demographic profile of the present cohort (67.2 years in the PFN group and 70.5 years in the PFN-A group). Female representation varied between implant groups (51% in the PFN cohort and 29% in the PFN-A cohort), reflecting the heterogeneous gender distribution observed in Indian trauma series, where fracture epidemiology is influenced by both osteoporosis-related fragility mechanisms and high-energy injuries.[1,4] Unstable fracture configurations (AO/OTA 31-A2.3 to A3) constituted 79% of cases, in keeping with patterns reported across Asian populations, where road traffic accidents contribute to injuries in younger males, while low-energy falls predominate among elderly females.[5]

The distribution of fracture subtypes in the present study (A3: 50%; A2: 40%) parallels findings reported by Sharma et al., who documented unstable patterns in approximately 70% of cases and by Kashid et al., where A2 and A3 fractures predominated. These observations reinforce the clinical preference for cephalomedullary fixation in unstable intertrochanteric variants, despite the recognised risk of postoperative varus collapse in osteoporotic bone.[6,7] Radiographic evidence of osteoporosis (Singh's index ≤3) was observed in 52% of patients overall (48% in the PFN group and 57% in the PFN-A group), comparable to the 48% to 55% prevalence reported in previous Indian studies utilising similar grading systems. This finding further supports the theoretical advantage of the PFN-A helical blade design, which facilitates cancellous bone compaction and improved anchorage in osteoporotic femoral heads.[1,8]

Operative duration was significantly shorter with PFN-A fixation (36.7 minutes) compared with PFN fixation (47.3 minutes), consistent with reduced technical complexity associated with single-blade insertion and avoidance of dual screw placement. Similar trends have been described by Sharma et al. (42 vs 52 minutes) and in earlier institutional data (36 vs 48 minutes).[1,6] Perioperative blood loss, estimated using haemoglobin drop (0.20% in PFN-A vs 0.42% in PFN), further emphasised the minimally invasive nature of cephalomedullary fixation. These findings are in agreement with observations by Kashid et al. and recent meta-analyses demonstrating a 20% to 30% reduction in blood loss with anti-rotation nail designs.[7,9]

Postoperative radiological parameters indicated comparable fixation quality between the two implant designs. The mean tip–apex distance (TAD) was 22.1 mm in the PFN group and 21.8 mm in the PFN-A group, with both values remaining below the widely accepted 25 mm threshold associated with increased risk of screw cut-out. Optimal implant positioning according to the Cleveland index was achieved in 92% to 95% of cases. These findings are consistent with recent clinico-radiological comparisons reporting equivalent TAD values of approximately 21.6 to 21.8 mm (p = 0.826) and a predominance of centre–centre or centre–inferior positioning in 52% to 60% of patients.[1,10] Restoration of the neck–shaft angle was also similar between groups (130.7^0 for PFN and 131.2^0 for PFN-A), with positive reduction achieved in 62% to 63% of cases. These observations correspond with contemporary PFNA-2 series reporting mean postoperative angles of approximately 131^0, as well as with the biomechanical recommendations of Yam et al., who emphasised maintenance of a neck–shaft angle greater than 128^0 to minimise the risk of varus collapse. The helical blade mechanism of PFN-A may offer an additional advantage in osteoporotic bone by promoting cancellous compaction and improved implant anchorage.[11,12] The high proportion of optimal Cleveland positioning in the present study (93%) compares favourably with previously reported ranges of 80% to 88% in recent systematic reviews and approximately 93% to 95% in earlier single-centre analyses, potentially reflecting improved intraoperative imaging protocols and precise postoperative assessment using PACS-based measurements.[1,7] Existing literature consistently identifies TAD and implant position as critical determinants of fixation success. Recent PFNA-2 studies have suggested an ideal TAD near 11.7 mm with negligible cut-out rates, while values exceeding 27 mm have been associated with significantly higher failure risk, as highlighted in updated analyses by Yam and colleagues.[11] The mean TAD below 23 mm achieved across the present cohort compares favourably with global averages reported between 24 and 26 mm.[12,13] By analysing a larger cohort with a substantial proportion of unstable, road-traffic-related injuries, the current study reinforces the equivalence of PFN and PFN-A in achieving satisfactory radiological outcomes, while underscoring the predominant influence of surgical reduction quality and implant positioning on fixation success across varying fracture stability patterns.[1,2]

Fracture union rates in the present study were high, with an overall rate of 97% at two-year follow-up (96% in the PFN group and 98% in the PFN-A group). Although long-term union rates were comparable, earlier radiological progression towards healing was more frequently observed following PFN-A fixation, with 89% demonstrating callus formation at six weeks compared with 82% in the PFN cohort. This trend may be attributable to the cancellous bone compaction achieved by the helical blade design, which enhances rotational stability and promotes early biological fixation within the femoral head.[1,10] These results compare favourably with the 92% union rate at six months reported by Sharma et al. and are consistent with contemporary PFNA series from 2024 documenting union rates of 95% to 98% at one-year follow-up, particularly in unstable fracture configurations. The predominance of unstable patterns in the present cohort (79%) further reflects the injury spectrum reported in Indian trauma populations with a high proportion of high-energy mechanisms.[6,12] Subgroup analysis of osteoporotic fractures (Singh's index ≤3; n = 149) demonstrated a statistically significant advantage for PFN-A fixation, with union achieved in 98% of cases compared with 94% in the PFN group (p = 0.04). Similar findings have been described by Kristek et al. and in recent PFNA-2 studies from 2025, which reported union rates approaching 97% in osteoporotic bone. The improved performance of the helical blade in this setting is likely related to trabecular densification and enhanced resistance to rotational instability and varus collapse compared with conventional dual-screw constructs.[8,12] Evidence supporting earlier radiological union with PFN-A has also been noted by Kashid et al., who observed healing in 85% of PFN-A cases versus 78% of PFN cases at six weeks. The extended two-year follow-up in the present study further demonstrates sustained fixation stability and successful progression to union beyond the shorter observation periods reported in many previous series.[7] By incorporating a comparatively large cohort with serial radiographic assessment, the current study contributes additional evidence regarding the role of implant design in fracture healing dynamics. While overall union rates were similar between implants, PFN-A fixation showed a consistent advantage in early healing and in osteoporotic subgroups. These findings are particularly relevant in the context of unstable, high-energy fracture patterns and reinforce the importance of optimal implant positioning and maintenance of a tip–apex distance below 25 mm, factors that have been associated with reduced non-union rates in both regional and international studies.[9,14]

Overall complication rates in the present study were low and comparable between implant groups (6.2% in the PFN cohort and 5.6% in the PFN-A cohort). The most frequent implant-related issue following PFN fixation was the Z-effect or reverse Z-effect phenomenon (n = 6), whereas cases treated with PFN-A predominantly demonstrated implant migration (n = 4). No statistically significant difference was observed between the two constructs (p = 1.0) and most complications were associated with suboptimal surgical parameters, particularly a tip–apex distance exceeding 25 mm or inadequate fracture reduction.[1,10] These findings are consistent with recent systematic reviews reporting overall complication rates of approximately 5% to 8% for cephalomedullary fixation and with biomechanical analyses demonstrating greater resistance to cut-out forces with newer PFNA-II designs. The relatively lower complication rates observed in the present cohort compared with earlier reports by Hohendorff et al. (7% to 10%) may be attributable to a higher proportion of optimal implant positioning and reduction quality.[12,15,16]

Functional outcomes were similar between the two implant groups, with mean HHS of 80.0 following PFN fixation and 80.1 following PFN-A fixation. Good-to-excellent results were achieved in 92% of patients, consistent with contemporary PFNA-2 studies reporting mean scores in the range of 85 to 90 and with previously published Indian series demonstrating values between 78 and 82. Although shorter operative duration and earlier mobilisation following PFN-A fixation may contribute to faster initial recovery, long-term functional outcomes appear comparable once fracture union is achieved.[12,17] Recent meta-analyses have similarly reported no significant difference in postoperative functional scores between cephalomedullary implant designs, underscoring the greater clinical importance of accurate reduction and implant positioning compared with implant choice alone.[18]

Existing literature continues to highlight implant-specific complications such as the Z-effect phenomenon in 2% to 6% of dual-screw PFN constructs and cut-out rates of approximately 1% to 3%, particularly in cases with wide femoral canals or inadequate fracture reduction. Single-blade designs have been associated with reduced rotational instability and lower rates of these complications in recent biomechanical and clinical analyses.[19,20] By analysing a relatively large cohort with serial radiographic follow-up extending to two years, the present study demonstrates favourable safety outcomes, with complication rates lower than those reported in several smaller series (8% to 12%). These findings support the safe and effective use of both PFN and PFN-A implants in intertrochanteric fractures, including in populations with high-energy injury patterns and underlying osteoporosis, provided that established radiological targets such as optimal TAD and implant positioning are consistently achieved.

The present study has certain limitations that should be acknowledged while interpreting its findings. The retrospective design introduces the possibility of selection bias in implant choice and incomplete availability of preoperative radiographs, which may have affected the accuracy of fracture classification and assessment of injury mechanisms. Follow-up imaging was not uniformly available, with only 68% of patients completing the two-year evaluation, thereby potentially leading to underestimation of late complications or fixation failures. Furthermore, the absence of prospective randomisation and surgeon blinding limits the ability to establish causal relationships between implant design and clinical outcomes. Osteoporosis assessment was based on radiographic grading using Singh's index without confirmation through dual-energy X-ray absorptiometry, restricting precise evaluation of bone mineral density. Functional outcomes were derived from available clinical records and incomplete documentation may have introduced reporting bias, potentially influencing the comparability of HHS between groups. Future multicentre prospective studies with standardised imaging protocols, objective bone density assessment and structured functional follow-up are warranted to validate these findings.

CONCLUSION

Cephalomedullary fixation using both PFN and PFN-A demonstrated satisfactory radiological and functional outcomes in the management of intertrochanteric fractures. High rates of fracture union, low complication profiles and comparable long-term functional recovery were observed when established surgical principles were consistently followed. PFN-A fixation was associated with certain perioperative advantages, including reduced operative time, lesser haemoglobin drop, earlier radiological progression towards union and improved outcomes in osteoporotic subgroups. Notwithstanding these differences, overall fixation success was predominantly influenced by intraoperative reduction quality and accurate implant positioning, particularly maintenance of a TAD below 25 mm and achievement of optimal Cleveland index placement. These findings emphasise that adherence to sound biomechanical and technical principles remains more critical than implant choice alone in determining clinical outcomes. Both PFN and PFN-A can therefore be considered safe and effective options for the treatment of unstable intertrochanteric fractures. Further prospective, multicentre studies with longer follow-up are warranted to refine implant selection strategies and guide evidence-based surgical decision-making.

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