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RESEARCH

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Assessing potential factors leading to perioperative peri-implant fracture in femoral pertrochanteric fracture osteosynthesis using the proximal femoral nail antirotation 2: A retrospective study

Jiun-Jen Yang[1], Yung-Heng Hsu[1], Ying-Chao Chou[1], Ping-Jui Tsai[1], Chang-Heng Liu[1] and Yi-Hsun Yu[1,2*]

Abstract

Background Perioperative peri-implant fractures (PPIFs) pose infrequent yet significant challenges in orthopedic surgery, particularly in the context of femoral pertrochanteric fractures (FPF) treated with proximal femoral nail antirotation 2 (PFNA-2) nails. PPIFs can lead to prolonged recovery and may necessitate re-osteosynthesis in severe cases. Despite the effectiveness of PFNA-2 in the management of FPFs, our understanding of PPIFs in this specific context remains limited. This study aimed to elucidate the factors contributing to PPIFs in patients with PFNA-2-treated FPF.

Methods In this retrospective analysis spanning from 2019 to 2022, patients with FPF treated with PFNA-2 nails were examined. Demographic data, fracture characteristics, and radiological parameters were collected, along with details of the PPIF management strategies and rehabilitation protocols. Radiological assessments included femoral morphology measurements and reduction and fixation quality evaluation. *The area under the curve (AUC) was analyzed in this specific group.*

Results Among 157 patients, 3.2% experienced acute PPIFs managed conservatively with successful union without secondary surgical intervention. Younger age and increased femoral isthmus diameter (DI) emerged as significant predictors of PPIFs in the univariate regression analyses ($P = 0.01$). *The AUCs for age (65.5 years) and DI (1.4 cm) were 0.78 and 0.79, respectively, indicating moderate accuracy.*

Conclusions Although PFNA-2 nails are reliable in managing FPFs, the persistence of PPIFs emphasizes their complex causes. This study highlights that younger age and increased femoral DI are crucial factors for PPIF occurrence in patients with PFNA-2-treated FPF. Conservative treatment with delayed weight-bearing ambulation may be effective in treating these fractures.

*Correspondence:
Yi-Hsun Yu
alanyu1007@gmail.com
Full list of author information is available at the end of the article

Keywords Pertrochanteric fractures, Peri-implant fractures, Proximal femoral nail antirotation 2, Intramedullary nail, Osteosynthesis

Background

Perioperative peri-implant fractures (PPIFs) manifest after the placement of osteosynthesis implants during the perioperative stage. These fractures are infrequent and demonstrate significant variability across various studies, with some reporting an incidence of PPIF ranging from 1 to 3% [1, 2]. In cases of greater displacement, PPIFs pose a challenging complication, which often requires repeated osteosynthesis procedures [3–5]. The precise etiology underlying the prevalence of PPIFs remains elusive, with an ongoing inquiry into whether factors such as reduction quality, implant size, or morphology of the fractured bones contribute to their occurrence [6–8].

Femoral pertrochanteric fractures (FPF) account for approximately 45% of all femur fractures [9–11]. Despite the effectiveness of treatment using a dynamic hip screw (DHS) [12, 13], the most widely accepted method for treating these fractures involves the use of a cephalomedullary nail (CMN), which is a well-established approach supported by robust evidence [14, 15]. The use of CMN demonstrates a high success rate in bone healing, and complications are infrequent, making it suitable for a diverse range of patients [1, 16–18]. Among the applied CMNs, a considerable body of evidence supports the notion that the proximal femoral nail antirotation 2 (PFNA-2) nail (DePuySynthes, Paoli, PA, US) provides many advantages and favorable outcomes in the treatment of FPFs [19, 20]. This implant ensures stable fixation, minimal blood loss, and shorter operation times, which allow early functional exercise that leads to excellent outcomes [21]. This implant also has a low complication rate, including cut-out, shortening, and varus malalignment, and offers superior functional outcomes compared with other devices [22].

Despite the reported positive outcomes of PFNA-2 nails, a comprehensive investigation of the occurrence of PPIFs is lacking. The determinants of PPIF when employing a PFNA-2 nail for FPF lack definitive evidence [22, 23]. Given the widespread use of PFNA-2 nails in managing such fractures, we aimed to elucidate the prospective factors contributing to PPIF in the context of treating FPFs using a PFNA-2 nail.

Methods

Data collection

This retrospective study included patients with FPFs who underwent PFNA-2 osteosynthesis at a single institution between January 2019 and December 2022. The ethical considerations of the Institutional and National Research Committee and the 1964 Helsinki Declaration and its later amendments were observed throughout the study. The research protocol was approved by the Institutional Review Board (IRB: 202301241B0), and patient confidentiality was maintained. Data were anonymized to ensure privacy; hence, the requirement for written informed consent was waived.

Individuals aged 18 years or older who underwent osteosynthesis for FPFs using a PFNA-2 nail were included in this study. Pathological fractures and FPFs associated with fractures in the shaft or distal femur were excluded. PPIF was defined as a new fracture along the femur surrounding the implanted device, identified after the surgical procedure. Patients were required to have undergone complete medical and radiological follow-ups at 1-, 3-, 6-, or 12-month intervals for at least 12 months or until union. The demographic profiles, fracture patterns, imaging characteristics, and complications of patients were recorded and analyzed through a thorough review of medical records, radiographs, and electronic databases.

Management strategies for FPFs

FPF is divided into three primary types: using the Arbeitsgemeinschaft für Osteosynthesefragen classification system (2018 revision), A1 and A2 are classified as stable, and A3 is classified as unstable [24]. Stable fractures are predominantly managed using short nails [25]. Individuals with unstable fractures are advised to undergo treatment using long nails. The diameter of each nail was selected based on the diameter of the femoral medullary cavity after reaming [26, 27].

Management strategies for PPIF

PPIF may be detected intraoperatively through fluoroscopic examination or postoperatively through follow-up radiography. In cases where the new fracture and placement of PFNA-2 were assessed as stable, conservative management involving delayed weight-bearing ambulation was utilized for PPIF. Otherwise, revision of osteosynthesis was considered necessary.

Rehabilitation protocol

The typical post-osteosynthesis protocol includes flatfoot touchdown, weight-bearing-assisted walking, and isometric quadriceps strengthening. The patients were instructed to only stand up with assistance and progress to independent mobility as tolerated. Emphasis was placed on active and passive range of motion exercises for the knees.

However, after the identification of PPIF in patients with FPF, a more conservative rehabilitation approach was adopted. Patients with stable PPIFs were prescribed a non-weight-bearing rehabilitation regimen for a minimum of 6 weeks postoperatively. Upon the detection of callus formation on follow-up radiography, walker-assisted partial weight-bearing ambulation was initiated. Full weight-bearing ambulation was permitted upon further callus development, approximately 3 months after the initial surgery.

Radiological evaluations

Considering the influence of proximal femur geometry on PPIF, measurements were performed for the morphology of the femur (MoF). These included the isthmus diameter (DI), lesser trochanter width (LTW), low-LTW (cavity width 20 mm below the mid-lesser trochanter line), and canal flare index (DI-to-LTW ratio in the anteroposterior view) [28, 29]. The measurements are shown in Fig. 1A.

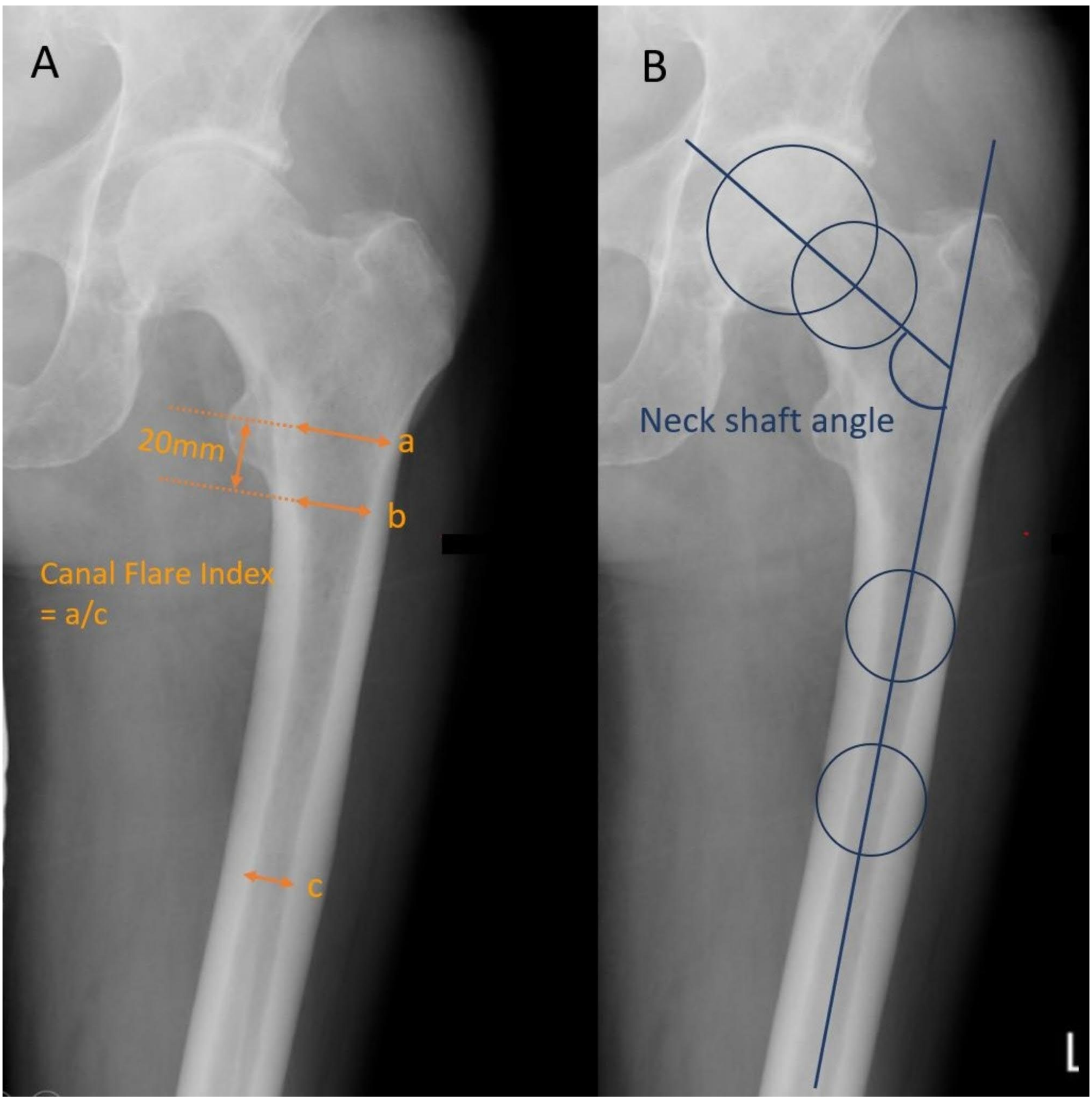

Fig. 1 Radiological assessments of the morphological characteristics of the femur. (**A**) Cavity width at the mid-lesser trochanter level (**a**); Cavity width 20 mm below the mid-lesser trochanter level (**b**), referred to as the low-lesser trochanter width; and isthmus diameter (**c**). The canal flare index was calculated as the ratio between parameters (**a**) and (**c**). (**B**) Neck-shaft angle measurement

The quality of reduction (QoR) was evaluated using the postoperative femoral neck-shaft angle [30] and medial femoral cortical support [31]. The neck-shaft angle was determined following the method described by Boese et al., which involves measuring the angle between the femoral neck axis and the femoral shaft axis on a plain anteroposterior radiograph (Fig. 1B). The measured angle of the affected femur was then compared to that of the healthy femur. QoR was categorized as "good" if the difference was less than 5 degrees, "acceptable" if between 5 and 10 degrees, and "poor" if exceeding 10 degrees. Additional radiological parameters included varus (neck-shaft angle < 125°) or valgus (neck-shaft angle > 125°) alignment [20] and medial femoral cortical support as positive, neutral, or negative [31].

The quality of fixation (QoF) was assessed based on the blade position using the Cleveland index and tip-apex distance (TAD) [32]. The Cleveland index utilizes the division of the femoral head into nine zones when assessing the position of the implant tip following osteosynthesis, particularly from an axial view [10]. The TAD was determined by adding the distance from the tip of the blade to the apex of the femoral head on the anteroposterior radiograph to the same distance on the lateral radiograph [33]. A consensus holds that a greater TAD is often correlated with a higher likelihood of implant cut-out.

The radiological parameters were evaluated by two independent surgeons using measurement tools embedded in the Picture Archiving and Communication System (PACS; Centricity Enterprise Web V3.0; GE Healthcare, Chicago, USA). All measurements were calibrated to the respective nail sizes on the radiographs using the PACS software. In case of discrepancies, a third senior surgeon made the final decision.

Statistical analysis

Descriptive statistics were used to summarize the demographic and clinical characteristics of patients. The Mann–Whitney U test was used to compare continuous variables, such as age and body mass index, between the groups. Fisher's exact test was used to analyze the associations for categorical variables. Univariate analysis employing binary regression was conducted to retrieve the odds ratios (ORs) and assess the association between independent variables and outcomes of interest, with statistical significance set at $P < 0.05$. Receiver operating characteristic (ROC) curves were evaluated to determine potential cut-offs and accuracy. All analyses were conducted using SPSS (IBM Corp. Released 2010. IBM SPSS Statistics for Windows, Version 19.0).

Results

Among the 157 patients enrolled, five (3.2%) patients experienced acute PPIFs. All PPIFs were identified either through intraoperative fluoroscopic examination (three out of five) or immediate postoperative X-ray examination (two out of five). They were either non-displaced or minimally displaced and were managed conservatively (Fig. 2). Three of these cases involved fracture sites located at the proximal medial anterior side of the femur, with one each occurring at the posterolateral and posteromedial positions. All patients received nonoperative treatment, and all PPIFs achieved union at the 6-month follow-up without any complications.

To identify potential contributors to PPIF, the cohort was stratified into two categories: individuals exhibiting PPIF and those without PPIF (Table 1). Within the spectrum of the considered variables, age emerged as one of the determinants associated with PPIF, particularly the prevalence among younger demographics within the PPIF cohort ($P = 0.04$). Regarding the MoF examined, a significant association was found between the DI and the occurrence of PPIFs ($P = 0.03$). However, when we analyzed the ratio of the DI to the inserted nail diameter, the results were not statistically significant ($P = 0.19$). The QoR results did not show significant differences between groups in either neck-shaft angle difference ($P = 0.73$) or anteromedial cortex reduction support ($P = 0.38$). When evaluating the factors regarding the nail design and QoF, no significant differences were observed among the selected variables. The detailed results are presented in Table 2.

In the univariate logistic regression analysis examining the predictors for PPIFs, age (OR = 0.95, 95% confidence interval [CI] = 0.01–0.02, $P = 0.01$) and DI (OR = 1.04, 95% CI = 1.00–1.09, $P = 0.04$) emerged as statistically significant factors associated with PPIFs (Table 3). The ratio between the DI and inserted nail diameter did not reach statistical significance in the univariate logistic regression ($P = 0.23$). >The ROC curves for age and DI had optimal cut-offs at 65.5 years, with an AUC of 0.778 (95% CI = 0.49-1, $P = 0.04$), and 1.4 cm, with an AUC of 0.789 (95% CI = 0.64–0.94, $P = 0.03$), respectively. The results of the prediction models are shown in Figs. 3 and 4.

Discussion

Although the incidence of PPIFs is relatively low compared with that of other orthopedic complications [34], it remains significant because of the possible re-osteosynthesis and its adverse impact on the quality of life of patients. PPIF is undesirable for both patients and surgeons; thus, emphasizing the importance of investigating the potential factors underlying its etiology. The findings of our study indicate that age and DI are significantly associated with the occurrence of PPIFs, with younger

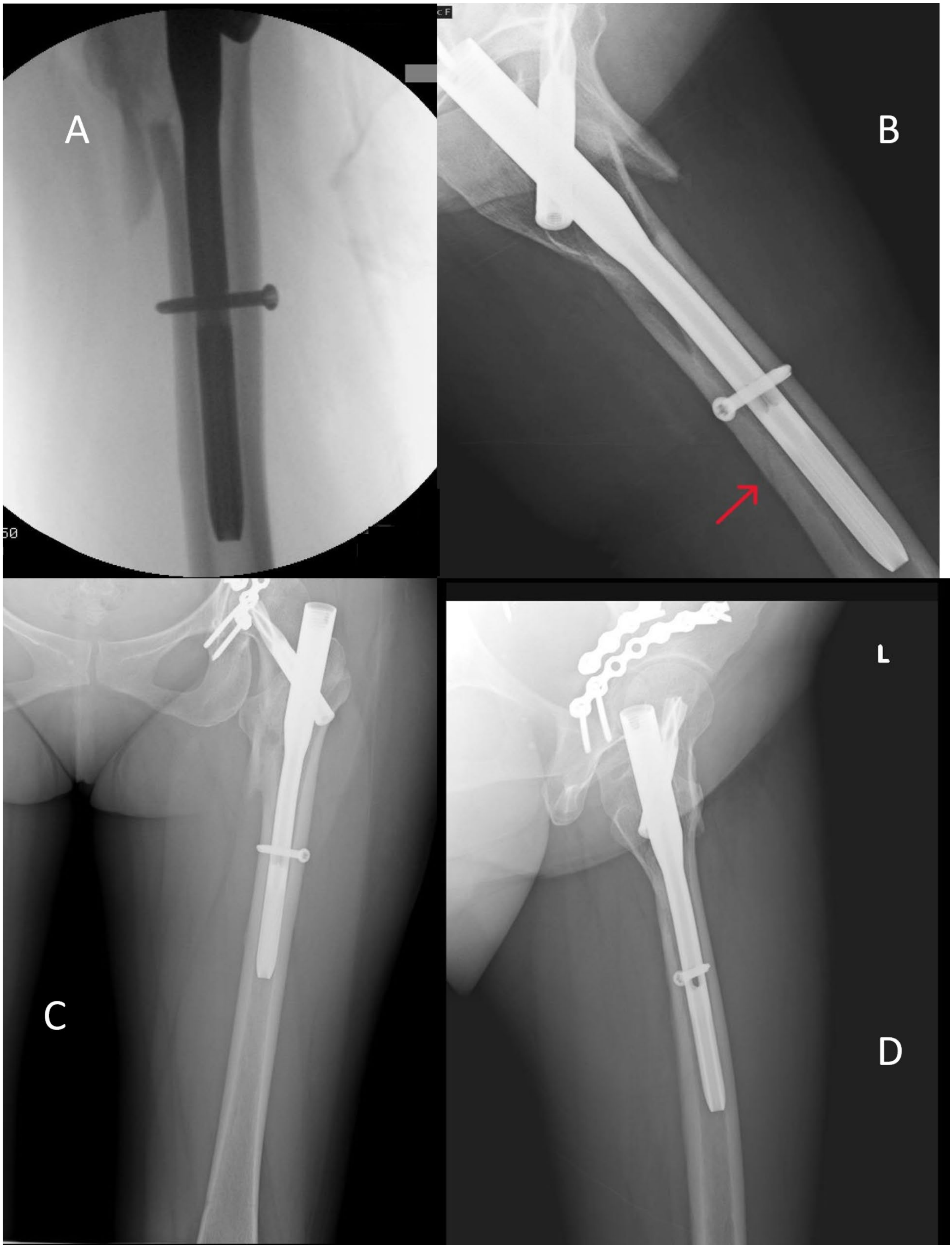

Fig. 2 An illustration depicting the progression of PPIF under conservative treatment. (**A**) Initially, a femoral intertrochanteric fracture was managed with osteosynthesis. (**B**) Subsequently, PPIF was discovered after surgery, and nonoperative treatment was pursued (indicated by an arrow). (**C**) Two months later, the follow-up radiography of the PPIF showed a healed fracture in the anteroposterior view. (**D**) Lateral view of the femur 2 months post-operation. PPIF, perioperative peri-implant fracture

Table 1 Patient demographics, PFNA-2 nail size, femoral canal morphology, and type of intertrochanteric fracture

	With PPIF (*n* = 5)	Without PPIF (*n* = 152)	*P*-value
Patient demographics			
Age (year)	64.00 (40.50–77.50)	80.00 (71.00–88.00)	0.04*
Sex			0.65
Male	1 (20.00%)	56 (36.80%)	
Female	4 (80.00%)	96 (63.20%)	
Body height (cm)	160.00 (150.00–169.50)	157.00 (151.50–165.00)	0.51
Body weight (kg)	55.00 (44.00–67.50)	57.00 (48.00–65.00)	0.59
BMI	19.53 (18.64–25.57)	22.60 (22.06–25.82)	0.32
Femur parameters			
Mid lesser trochanter width	2.57 (2.31–2.83)	2.51 (2.13–2.89)	0.78
Low lesser trochanter width	1.96 (1.63–2.29)	1.89 (1.59–2.19)	0.59
Isthmus diameter	1.64 (1.46–1.75)	1.41 (1.23–0.56)	0.03*
Ratio (mid/isthmus)	1.61 (1.37–1.85)	1.82 (1.47–2.17)	0.13
Ratio (low/isthmus)	1.22 (1.02–1.42)	1.38 (1.13–1.63)	0.07
Fracture side			0.29
Left	1 (20.00%)	85 (55.90%)	
Right	4 (80.00%)	67 (44.10%)	
Fracture type			0.39
Stable	1 (20.00%)	67 (44.10%)	
Unstable	4 (20.00%)	85 (55.90%)	

*$P < 0.05$ was considered statistically significant

PFNA-2, proximal femoral nail antirotation 2; PPIF, perioperative peri-implant fracture; BMI, body mass index

Table 2 Nail design, quality of reduction, and quality of fixation in patients with post-PFNA2 osteosynthesis

	With PPIF (*n* = 5)	Without PPIF (*n* = 152)	*P*-value
Nail design			
Length			0.87
Short	4 (80.00%)	116 (76.31%)	
Long	1 (20.00%)	36 (23.69%)	
Diameter (mm)			0.81
9	0	12 (7.89%)	
10	2 (40.00%)	53 (34.86%)	
11	3 (60.00%)	57 (37.55%)	
*Neck-shaft angle difference (degree)**			*0.73*
Good < 5	*4 (80.00%)*	*118 (77.63%)*	
Acceptable > 5, < 10	*1 (20.00%)*	*33 (21.71%)*	
Poor > 10	*0*	*1 (0.66%)*	
Anteromedial cortex reduction support			0.38
Negative	1 (20.00%)	11 (7.24%)	
Neutral	3 (60.00%)	127 (83.56%)	
Positive	1 (20.00%)	14 (9.21%)	
Tip to apex distance (cm)	1.39 (0.77–2.00)	1.22 (0.83–1.61)	0.53
Cleveland index			0.47
1	0	4 (2.63%)	
2	3 (60.00%)	36 (23.68%)	
3	0	3 (0.66%)	
4	0	1 (71.11%)	
5	2 (40.00%)	108 (71.11%)	

PFNA-2, proximal femoral nail antirotation 2; PPIF, perioperative peri-implant fracture

**Neck-shaft difference is defined as the difference in the neck-shaft angle between the affected and the unaffected femur*

Table 3 Univariate logistic regression analysis of the predictors for perioperative peri-implant fractures

Variable	OR (95% CI)	*P*-value
Age (year)	0.95 (0.91–0.99)	0.01*
Sex (Male)	2.33 (0.25–21.40)	0.45
Body height (cm)	1.02 (0.92–1.13)	0.68
Body weight (kg)	0.99 (0.92–1.06)	0.70
BMI	0.92 (0.74–1.15)	0.47
Nail diameter	1.32(0.29–6.21)	0.71
Tip to apex distance (cm)	1.01 (0.99–1.03)	0.34
Side (Left)	5.08 (0.55–46.47)	0.15
Mid lesser trochanter width (cm)	1.00 (0.98–1.02)	0.73
Low lesser trochanter width (cm)	1.00 (0.97–1.04)	0.64
Diameter of isthmus (cm)	1.04 (1.01–1.08)	0.04*

*$P<0.05$ was considered statistically significant

OR, odds ratio; CI, confidence interval; BMI, body mass index

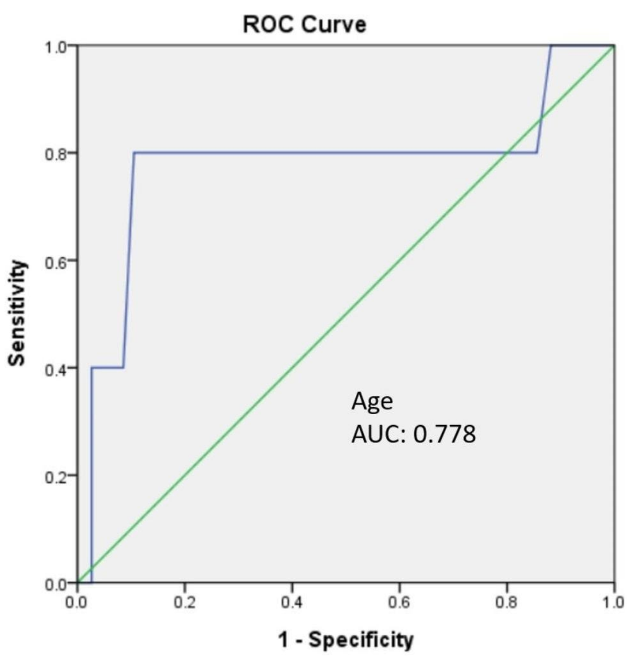

Fig. 3 ROC curve for age in predicting the complication of PPIF. The ROC was 0.778, with a cut-off at 65.5 years. ROC, receiver operating characteristic; PPIF, perioperative peri-implant fracture

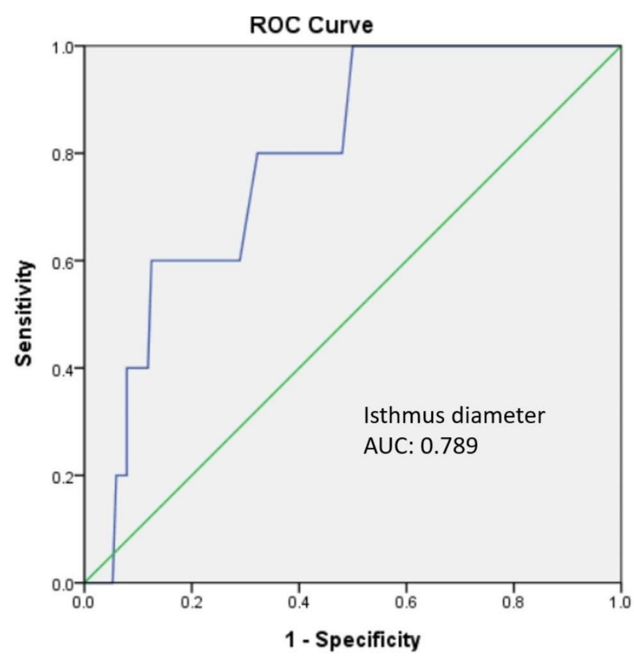

Fig. 4 ROC curve for isthmus diameter in predicting the complication of PPIF. The ROC was 0.789, with a cut-off at 1.4 cm. ROC, receiver operating characteristic; PPIF, perioperative peri-implant fracture

patients and those with a larger DI of the proximal femur being more likely to experience such fractures.

In previous studies, Muller et al. [35] reported a higher incidence of peri-implant femoral fractures with PFNA-2 nails than with DHS, suggesting a potential risk factor for the use of PFNA-2 nails [15, 35]. Based on our experience, when employing a fixation implant to treat FPFs, the PFNA-2 nail proved to be a reliable implant with a high union rate and minimal complication rate; however, PPIFs were still present in this study. We found that the design of the PFNA-2 nail did not cause PPIFs, which is consistent with previous studies that assessed implant nail lengths [36, 37]. Furthermore, given that inadequate fracture reduction may influence the incidence of PPIF, our study did not detect such an association because all QoR scores within our cohort ranged from fair to good.

Using ROC curve analysis, we explored two variables (age and DI) that might contribute to the occurrence of PPIFs. Although the cut-off value for age was 65.5 years, younger patients were more prone to developing PPIFs than older patients. This highlights a previously overlooked aspect of the literature regarding the impact of age on PPIF incidence [38]. We hypothesized that during the insertion of the nail by hammering, the large nail head would exert direct pressure on the femur. Given the greater hardness of the femoral cortex in younger patients than in older patients, we anticipated a higher incidence of PPIFs.

Furthermore, we identified a significant correlation between femoral DI and the likelihood of PPIF occurrence. A larger DI may increase the risk of fracture because the nail is eccentrically inserted, which may induce fractures around the nail tip or shaft during hammering [39]. This highlights the importance of considering the anatomical factors when assessing and preventing PPIFs. In addition, the ratio between the DI and inserted nail diameter did not reach significance when comparing the fracture and non-fracture groups. Based on our findings, we propose that a denser femoral cortex in younger patients and the use of an eccentricity-oriented approach during nail insertion into a wider femoral isthmus may contribute to the observed associations.

Although some studies have advocated that stress concentration at the tip of the initial intramedullary nail and the distal interlocking screw area may be key factors in PPIFs after fixation of intertrochanteric fractures [38, 40], all our cases with PPIF were non-displaced, localized around the proximal part of the femur, discovered within 1 month, and treated nonoperatively. We postulated that the PPIFs in our cases might have occurred during nail introduction and that these fractures were relatively subtle. Therefore, conservative treatment was effective. Nonoperative management of peri-implant fractures, not just intramedullary nails, has been reported to be successful in various cases [40–42]. Although PPIF cases are rare, these still highlight the potential for conservative treatment of peri-implant fractures, although the specific criteria for nonoperative management require further investigation.

Our study has some limitations. The retrospective design and relatively small sample size introduce inherent biases and limitations in data collection and analysis, potentially leading to instability in model estimates. To mitigate this, ROC curve and AUC analyses were performed. However, despite these adjustments, the challenges posed by sparse data remain a limitation to the generalizability and precision of the results. Second, the determination of nail length relied on the judgment of the attending orthopedic surgeon on-site, whereas diameter selection was contingent upon the results of reaming, both of which contributed to the context-dependent nature of nail selection. The use of X-rays to measure femoral parameters may have lacked the precision of computed tomography scans. Moreover, if all patients receive conservative treatment, the achievement of their intended early weight-bearing goals may be hindered. The de-identification process for all cases and the inclusion of patients operated on by various orthopedic surgeons may have introduced bias. Large-scale studies with comprehensive data are required to address these limitations. The precise reasons for PPIFs occurring after PFNA-2 nails still lack firm and comprehensive data, and many factors remain debatable. Such studies should not only explore PPIF in PFNA-2 nails but also examine its application in other implants and reduction methods.

Conclusions

The findings of this study indicate that the PFNA-2 nail is a reliable implant with a high union rate and minimal complication rate for treating FPFs. Younger age and a wider femoral isthmus are potential factors associated with acute PPIFs. The occurrence of PPIFs cannot be fully ruled out; thus, attention should be paid intraoperatively by carefully examining fluoroscopy, as well as during postoperative follow-ups through imaging.

Abbreviations

PPIF	Perioperative peri-implant fracture
FPF	Femoral pertrochanteric fractures
PFNA-2	Proximal femoral nail antirotation 2
CMN	Cephalomedullary nail
DHS	Dynamic hip screw
MoF	Morphology of the femur
DI	Isthmus diameter
LTW	Lesser trochanter width
PACS	Picture Archiving and Communication System
QoR	Quality of reduction
QoF	Quality of fixation
TAD	Tip-apex distance
ORs	Odds ratios
CI	Confidence interval
ROC	Receiver operating characteristic
AUC	Area under the curve

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Author contributions
YHY, YCC, PJT, and JJY gathered, analyzed, and interpreted the patient data. YHH, JJY, CHL, and YHY were major contributors to the manuscript writing. All the authors have read and approved of the final version of the manuscript.

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

Declarations

Ethics approval and consent to participate
This retrospective chart review involving human participants was conducted in accordance with the ethical standards of the Institutional and National Research Committee and the 1964 Helsinki Declaration and its later amendments. The study protocol was approved by the Institutional Review Board (IRB no: 202301241B0) of Chang Gung Memorial Hospital, Taoyuan City, Taiwan, and the requirement for informed consent was waived because of the retrospective nature of the study.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Author details
[1]Division of Orthopaedic Traumatology, Department of Orthopaedic Surgery, Musculoskeletal Research Center, Chang Gung Memorial Hospital, Tao-Yuan 33302, Taiwan
[2]Department of Orthopedics, Chang Gung Memorial Hospital, No. 5, Fuxing St., Guishan Dist, Taoyuan City 33305, Taiwan

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