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ORIGINAL ARTICLE

The clinical efficacy of proximal femoral nail antirotation and proximal femoral bionic nail in the treatment of intertrochanteric fractures of the femur in the elderly: A systematic review and meta-analysis

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ABSTRACT

Objectives: In this systematic review and meta-analysis, we evaluate and compare the clinical efficacy and safety of proximal femoral nail antirotation (PFBN) and proximal femoral bionic nail (PFNA) for treating intertrochanteric fractures in elderly patients, with the goal of providing evidence-based recommendations for clinicians to select the most suitable internal fixation method.

Materials and methods: We conducted a literature search in the CNKI, PubMed, Cochrane, and Embase databases for studies on PFBN and PFNA in treating elderly intertrochanteric femoral fractures, with a search timeframe from database inception to November 2024. Two reviewers independently screened the literature according to the inclusion and exclusion criteria and extracted relevant data.

Results: A total of eight studies were included, involving 506 patients with intertrochanteric femoral fractures, with 225 in the PFBN group and 281 in the PFNA group. The meta-analysis results indicated that the PFBN group had a significantly shorter fracture healing time compared to the PFNA group (mean difference [MD]=–0.61, 95% confidence interval [CI]: –1.12 to –0.10, $p<0.01$), an earlier postoperative weight-bearing time (MD=–13.51, 95% CI: –22.38 to –4.64, $p< 0.01$), and a higher Harris Hip Score postoperatively (MD=0.93, 95% CI: 0.01 to 1.86), $p<0.05$). However, the surgical time in the PFNA group was significantly shorter than that in the PFBN group (MD=6.19, 95% CI: 2.35 to 10.03, $p<0.01$), and the intraoperative blood loss was also significantly less (MD=9.61, 95% CI: 0.57 to 18.65, $p<0.01$). There was no significant statistically significant difference in complication rates between the two groups.

Conclusion: The PFBN group exhibited a significantly shorter fracture healing time, earlier postoperative weight-bearing time, and better hip function after surgery in treating elderly intertrochanteric femoral fractures. However, the surgical time and intraoperative blood loss in the PFBN group were significantly greater than those in the PFNA group. Nonetheless, there were no significant differences in complication rates between the two groups. Therefore, PFBN remains an ideal internal fixation method for treating elderly intertrochanteric femoral fractures.

Keywords: Elderly, intertrochanteric fracture, proximal femoral bionic nail, proximal femoral nail antirotation.

Currently, with the continuous and rapid increase in the aging population, the number of hip fracture patients is also rising, of which 75% are intertrochanteric fractures.[1] Patients with hip fractures have a high rate of mortality and disability,[2] making surgical treatment the mainstream approach, as it can reduce the incidence of complications such as pressure sores, thrombosis, and aspiration pneumonia. Common internal fixation methods for intertrochanteric femoral fractures include intramedullary and extramedullary fixation.[3] Among these, intramedullary fixation is currently the primary method, with common types including proximal femoral nail antirotation (PFNA), Gamma, and InterTAN.[4] The PFNA is currently the most

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common method for treating elderly patients with intertrochanteric fractures. It has small surgical trauma, a short internal fixation moment, and can withstand large axial loads on the femur.[5] The proximal spiral blade compresses bone tissue, increasing its grip and shear resistance in the femoral head and neck. It also automatically locks the main nail, effectively preventing rotation and collapse of the proximal femoral fracture block, reducing hip inversion deformities and allowing early weight-bearing. However, as its application becomes more widespread, reports of internal fixation failure are increasing.[6,7] The presence of osteoporosis can lead to a decrease in the fixation power of internal fixation devices, prolonged fracture healing time, and an increased occurrence of fixation failure.

Proximal femoral bionic nail (PFBN) is a new type of internal fixation system, which is based on the "Proximal Femoral N-Triangle Theory" by Chinese scholar Zhang Yingze[8] and the "Lever-Balance-Reconstruction" theory by Zhang Dianying.[9] The human hip joint structure is similar to a lever system, and due to the differences between the femoral anatomical axis and the mechanical axis, as well as the formation of tension and compression trabeculae, the normal line of force in the lower limb has a support point near the center of the femoral head. The medial lever arm is short, and the lateral lever arm is long, therefore the hip joint can bear the body weight and perform various movements. As age increases, osteoporosis mainly occurs in the lateral trochanteric area, which is the main cause of hip fractures in the elderly. The type of proximal femoral fractures is linked to alterations in the lower limb force line and support point. Following a hip fracture, the normal anatomical structure is disrupted, the support point vanishes, and weight-bearing becomes impossible, resulting in hip inversion deformity. The PFBN internal fixation system establishes a new lever system to replace the original lever system. The support point reconstruction of the new internal fixation system, being closer to the anatomical physiological support point, offers high stability and mechanical advantages, resulting in a marked improvement in fixation effectiveness and reduced recovery time. The PFBN main nail is equipped with three screw holes for securing the traction screw, proximal support screw, and distal locking screw. The central section of the traction screw includes a nail hole through which the support screw passes, forming a cross pattern.[9-11] A large number of finite element analysis (FEA) studies confirm that PFBN has biomechanical advantages over traditional internal fixation in treating intertrochanteric fractures.[12,13]

In this systematic review and meta-analysis, we evaluate and compare the clinical efficacy and safety of PFBN and PFNA for treating intertrochanteric fractures in elderly patients, with the goal of providing evidence-based recommendations for clinicians to select the most suitable internal fixation method.

MATERIALS AND METHODS

This study was reported in accordance with the 2020 Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA)[14] and Assessing the Methodological Quality of Systematic Reviews (AMSTAR)[15] guidelines. The meta-analysis was registered in the International Prospective Register of Systematic Reviews (PROSPERO) with the registration number CRD42024609501.

Literature search

Searches were conducted in English databases CNKI, Cochrane, PubMed, and Embase from their inception to November 2024, using the search terms "([intertrochanteric fractures] OR [hip fractures] OR [intertrochanteric femoral fractures]) AND ([proximal femoral bionic nail] OR [PFBN]) OR ([proximal femoral nail antirotation] OR [PFNA])."

Inclusion and exclusion criteria

Included studies were considered eligible, if they met the following PICOS criteria:

Population: Patients with intertrochanteric femoral fractures and age ≥65 years;

Intervention: PFBN;

Comparator: PFNA;

Outcomes: Harris Hip Score (HHS), blood loss, operation time, fracture healing time, postoperative weight-bearing time, postoperative complications and length of hospital stay.

Study design: Randomized-controlled studies, prospective cohort studies and retrospective studies.

Only published clinical studies were included and the included studies were required to contain at least two outcome measures and a follow-up time of ≥6 months. Pathological fractures, conference abstracts, expert opinions, commentaries, meta-analyses, and case reports were excluded. Patients with fractures resulting from high-energy trauma and those with multiple fractures were also excluded from the study.

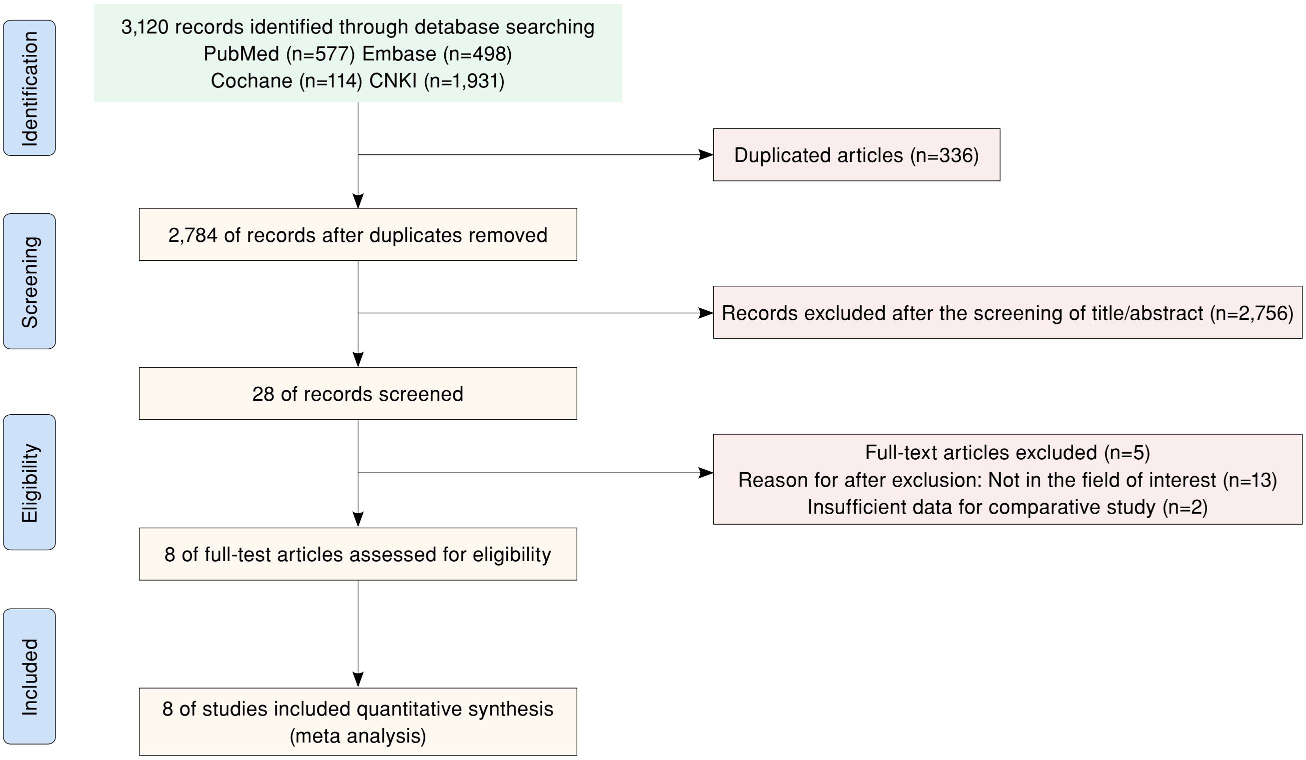

FIGURE 1. Study flowchart.

Data extraction

Two reviewers independently screened relevant literature according to the search strategy and cross-checked based on the inclusion and exclusion criteria. In cases of disagreement, the two reviewers discussed to reach a consensus, and if necessary, a third reviewer would arbitrate. Data extraction included: *(i)* Baseline characteristics of the studies, such as authors' names, publication year, study type, sample size, age, sex, AO classification of fractures, and follow-up duration; and *(ii)* Outcome measures including operation time, intraoperative blood loss, fracture healing time, weight-bearing time, final HHS, and complications.

Quality assessment of included studies

Two reviewers independently assessed the quality of the included studies. For

TABLE I
Baseline characteristics of studies

Author	Year	Study design	Cases (n)		Mean ages (year)		Sex (Male/Female)		AO Classification (A1/A2/A3)		Follow-up (months)
			PFBN	PFNA	PFBN	PFNA	PFBN	PFNA	PFBN	PFNA	
Li et al.[18]	2022	RS	46	46	75.7 (5.2)	75.3 (4.2)	22/24	20/26	6/28/12	5/30/11	6-12
Lin et al.[19]	2022	RS	20	25	78.7 (5.9)	78.7 (8.2)	6/14	7/18	4/7/9	6/9/10	6-21
Lin et al.[20]	2023	RS	28	28	70.4 (7.8)	73.0 (8.9)	12/16	10/18	4/16/8	2/16/10	>6
Wang et al.[21]	2023	RS	20	20	75.3 (6.4)	74.6 (6.0)	9/11	8/12	NA	NA	6-9
Yang et al.[22]	2023	RS	24	24	75.0 (5.0)	78.6 (5.8)	11/13	9/15	5/13/6	6/12/6	6-15
Jin et al.[17]	2024	RS	25	55	73.67 (5.16)	74.23 (5.57)	9/16	17/38	NA	NA	>12
Fu et al.[16]	2024	RS	22	40	76.27 (4.47)	79.15 (7.82)	10/12	13/27	6/7/9	14/7/19	≥6
Zhang et al.[23]	2024	RS	40	43	81.4 (9.1)	80.2 (11.6)	15/25	16/27	0/27/13	30/13	≥18

PFBN: Proximal femoral bionic nail; PFNA: Proximal femoral nail antirotation; RS: Retrospective studies; NA: Not available.

TABLE II
Risk of bias assessment using the ROBINS-I tool

Study	Year	Confounding	Selection	Intervention classification	Deviation from intervention	Missing data	Measurement of outcome	Selection of reported result	Overall
Li et al.[18]	2022	Low	Low	Moderate	Low	Low	Low	Low	Moderate
Lin et al.[19]	2022	Low	Moderate	Low	Low	Low	Low	Low	Low
Lin et al.[20]	2023	Low	Moderate	Moderate	Low	Low	Low	Low	Moderate
Wang et al.[21]	2023	Low	Low	Low	Low	Moderate	Low	Low	Low
Yang et al.[22]	2023	Low	Low	Low	Low	Low	Low	Low	Low
Jin et al.[17]	2024	Low	Moderate	Low	Low	Low	Moderate	Low	Moderate
Fu et al.[16]	2024	Low	Low	Low	Low	Low	Low	Low	Low
Zhang et al.[23]	2024	Low	Low	Low	Low	Low	Low	Low	Low

ROBINS-I: Risk Of Bias In Non-randomized Studies-of Interventions.

randomized-controlled trials, the Newcastle-Ottawa Scale (NOS) was used for quality assessment, with scores above 6 considered as high-quality literature. Non-randomized studies were assessed using the Risk Of Bias In Non-randomized Studies of Interventions (ROBINS-I) tool, with final results rated according to their overall risk of bias (low, moderate, serious, critical, or no information).

Statistical analysis

Statistical analysis was performed using the Stata version 14.0 software (STATA Corp., College Station, TX, USA). Continuous variables were expressed in weighted mean differences (WMD); standardized mean differences (SMD) were used when the units differed; and dichotomous variables were expressed as odds ratios (OR). In case of $p<0.1$ and $I^2>50\%$, significant heterogeneity was assumed, and a random-effects model was used for statistical analysis. In case of $p>0.1$ and $I^2<50\%$, low heterogeneity was assumed, and a fixed-effects model was applied. Sensitivity analysis was conducted to confirm the stability of the study results. When the number of included studies was ≥10, Egger's test was used to analyze publication bias, with a significance level set at $\alpha=0.05$.

RESULTS

Literature search results

A preliminary search yielded 3,120 articles, and after excluding duplicates, articles not meeting inclusion criteria, and those with inaccessible data, a total of eight studies[16-23] were included (Figure 1). All included studies were retrospective cohort studies, involving a total of 506 patients with intertrochanteric fractures, with 225 in the PFBN group and 281 in the PFNA group. Overall characteristics of each study are shown in Table I.

Quality assessment

Since all included studies were retrospective cohort studies, the ROBINS-I tool was used to assess the quality of the eight studies, which showed 5 at low risk, 3 at moderate risk, and 0 at serious risk. Quality assessments of each study are detailed in Table II.

Meta-analysis results

Operation time

In these eight studies,[16-23] a comparison of operation times between the two groups revealed significant heterogeneity ($p<0.1$, $I^2=82.4\%$); therefore, a random-effects model was used for analysis. The combined effect size showed MD=6.19

(95% confidence interval [CI]: 2.35-10.03, Z=3.16, p<0.01). This indicates that the operation time in the PFNA group was shorter than in the PFBN group (Figure 2).

Intraoperative blood loss

Eight studies[16-23] compared intraoperative blood loss between the two groups, revealing significant heterogeneity (p<0.01, I^2=86.9%); therefore, a random-effects model was used for analysis. The combined effect size showed MD=9.61 (95% CI: 0.57-18.65; Z=2.08, p<0.05). This indicates that the PFNA group had less intraoperative blood loss compared to the PFBN group (Figure 3).

Fracture healing time

Six studies[16-20,23] compared fracture healing times between the two groups, and the results

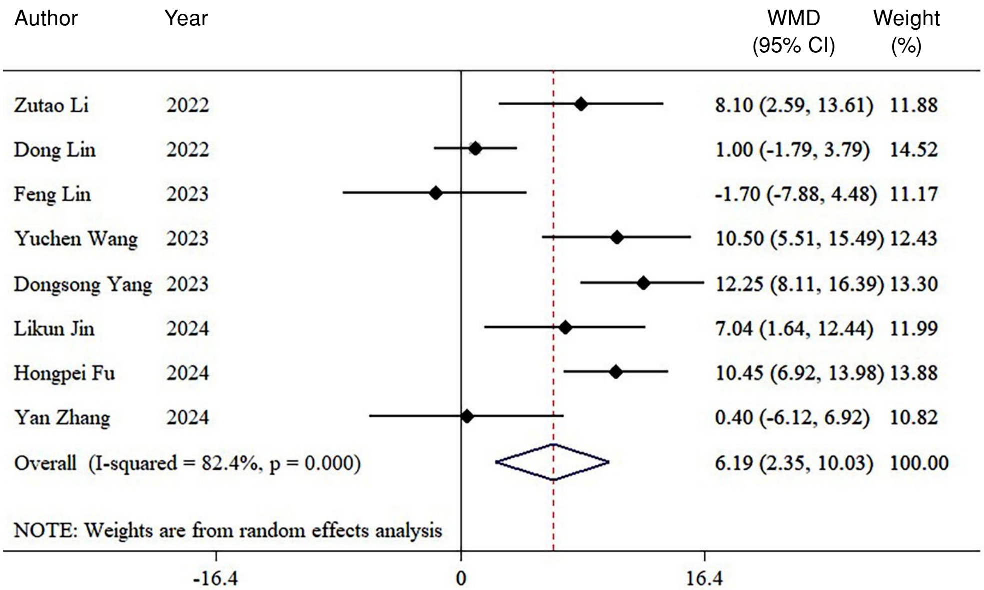

FIGURE 2. Forest plot of operation time.
WMD: Weighted mean differences; CI: Confidence interval.

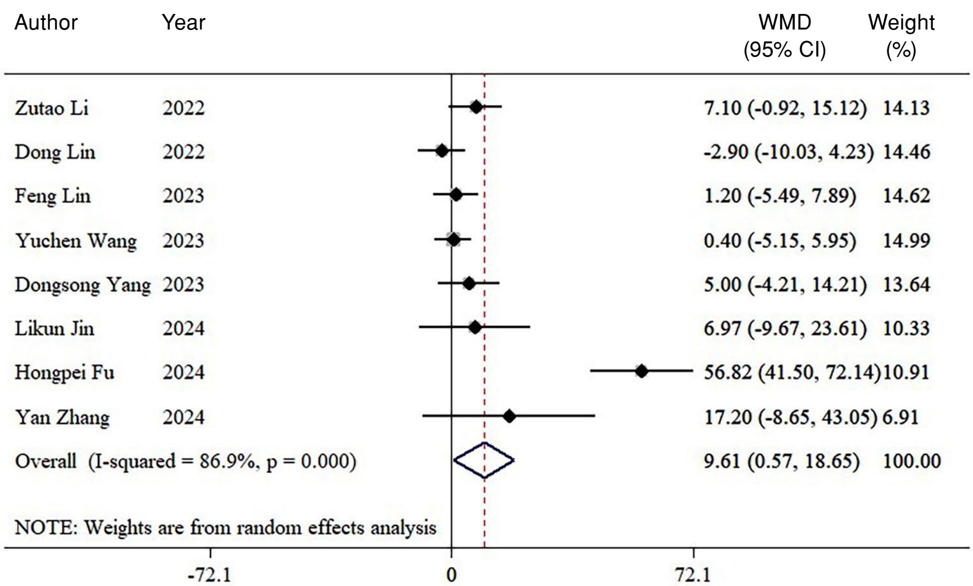

FIGURE 3. Forest plot of intraoperative blood loss.
WMD: Weighted mean differences; CI: Confidence interval.

showed significant heterogeneity ($p<0.01$, $I^2=82.1\%$), prompting the use of a random-effects model for analysis. The combined effect size showed MD=–0.61 (95% CI: –1.12-0.10; Z=3.36, $p<0.05$). This indicates that the fracture healing time in the PFBN group was shorter compared to the PFNA group (Figure 4).

Length of hospital stay

Six studies[16-18,21-23] compared length of hospital stay between the two groups, showing significant heterogeneity ($p<0.01$, $I^2=93.9\%$), thus a random-effects model was applied for analysis. The combined effect size showed MD=–0.86 (95% CI: –2.19-0.47; Z=3.01, p=0.205). This indicates no significant difference in length of hospital stay between the PFBN and PFNA groups (Figure 5).

Weight-bearing time

Six studies[17-20,22,23] compared postoperative weight-bearing time between the two groups,

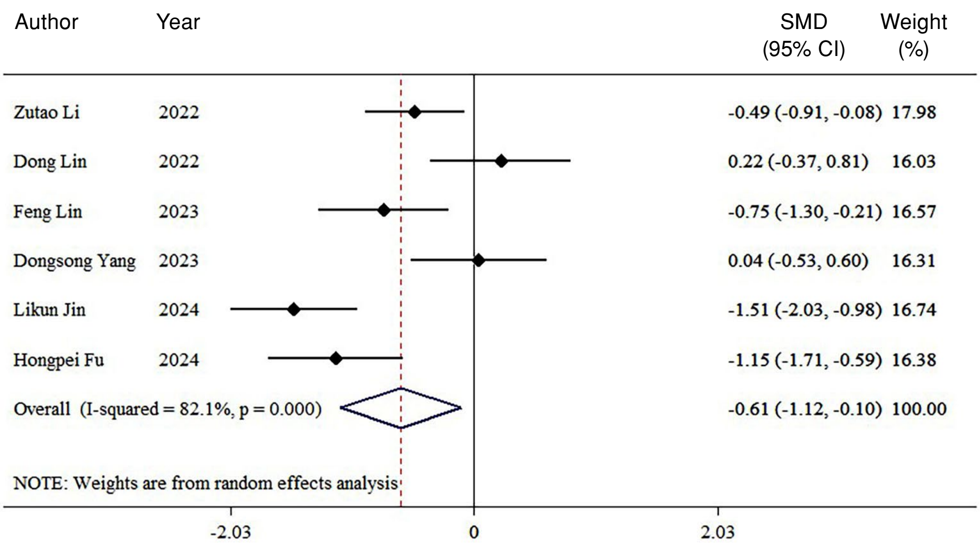

FIGURE 4. Forest plot of fracture healing time.
SMD: Standardized mean differences; CI: Confidence interval.

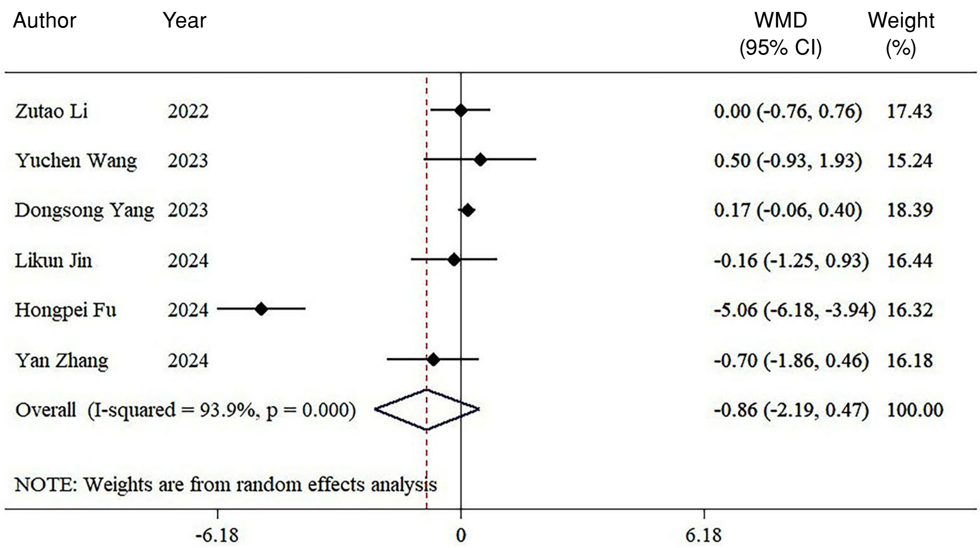

FIGURE 5. Forest plot of length of hospital stay.
WMD: Weighted mean differences; CI: Confidence interval.

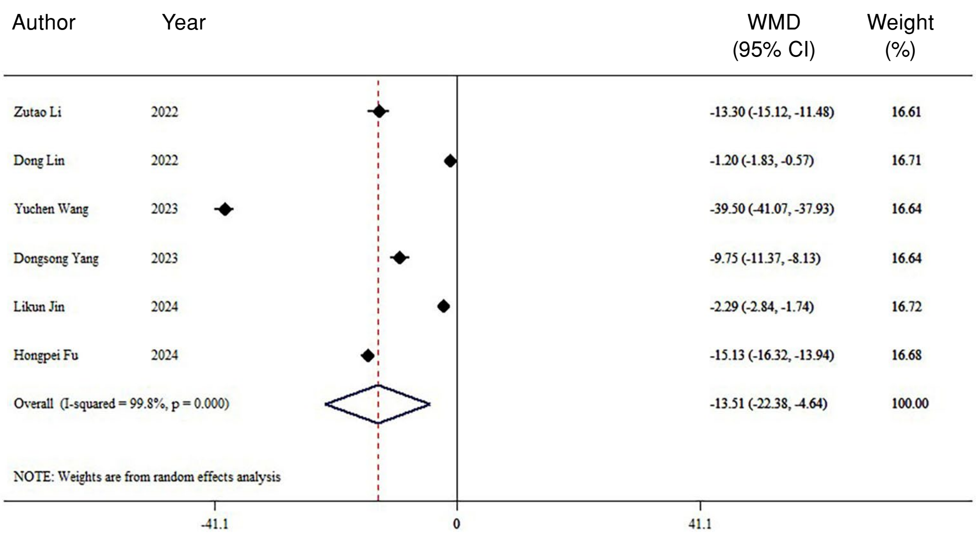

FIGURE 6. Forest plot of weight-bearing time.
WMD: Weighted mean differences; CI: Confidence interval.

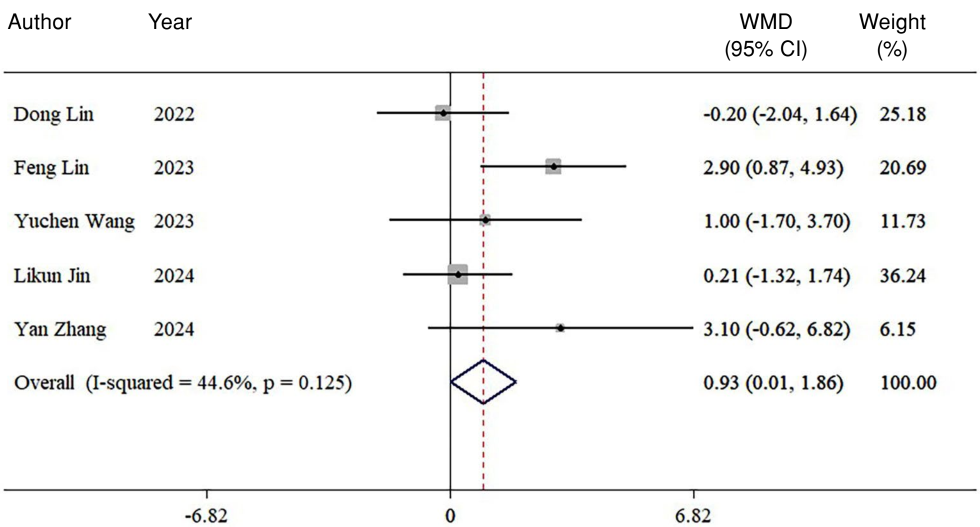

FIGURE 7. Forest plot of final Harris Hip Score at last follow-up.
WMD: Weighted mean differences; CI: Confidence interval.

showing significant heterogeneity ($p<0.01$, $I^2=99.8\%$), thus a random-effects model was applied for analysis. The combined effect size showed MD=–13.51 (95% CI: –22.38-4.64; Z=2.99, p=0.003). This indicates that the PFBN group began weight-bearing earlier compared to the PFNA group (Figure 6).

Final HHS at last follow-up

In five studies,[18,20-22] postoperative HHS scores were compared between the two groups, showing low heterogeneity ($p=0.125$, $I^2=44.6\%$), thus a fixed-effects model was applied for analysis. The combined effect size showed MD=0.93 (95% CI: 0.01-1.86; Z=1.98, p=0.048), indicating that the final HHS scores were higher in the PFBN group compared to the PFNA group (Figure 7).

Complications

In eight studies,[16-23] overall postoperative complications were compared between the two groups, revealing low heterogeneity ($p=0.487$, $I^2=0\%$), thus a fixed-effects model was used for analysis. The combined effect size showed MD=0.37 (95% CI: 0.14-1; Z=1.96, p=0.051). This indicates that

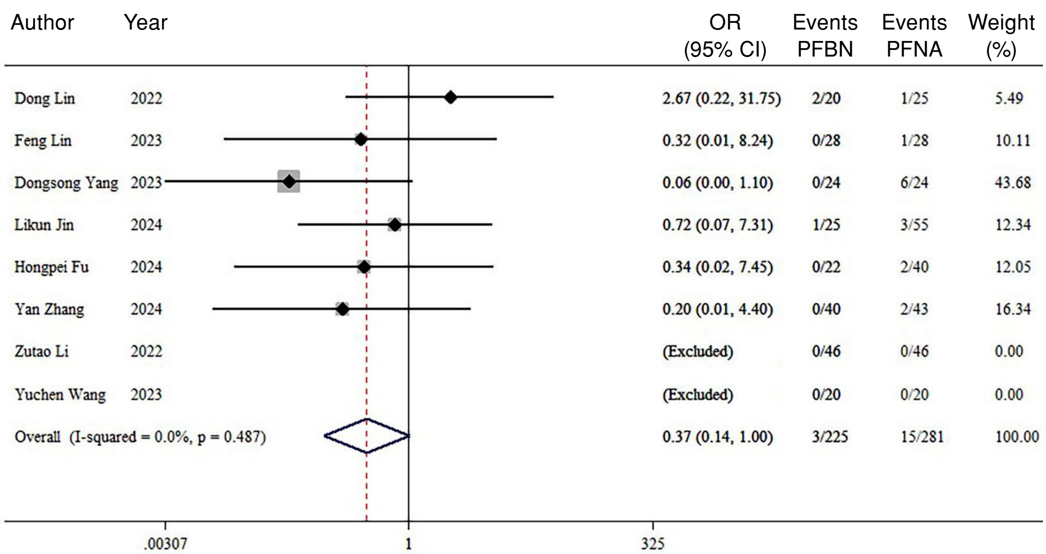

FIGURE 8. Forest plot of complications.
OR: Odds ratio; CI: Confidence interval; PFBN: Proximal femoral bionic nail; PFNA: Proximal femoral nail antirotation.

there was no significant difference in the incidence of postoperative complications between the PFBN and PFNA groups. The complication rate in the PFBN group was 1.3%, while in the PFNA group it was 5.3% (Figure 8).

Publication bias and sensitivity analysis

As there were fewer than 10 studies included for any outcome measure, a publication bias analysis was not necessary. Sensitivity analyses were conducted for the combined effect sizes of each outcome measure, removing one study at a time, and the results remained stable, confirming the robustness of the combined findings (see Supplementary Figures 1-6).

DISCUSSION

In this systematic review and meta-analysis, we found that the PFBN group experienced shorter fracture healing times compared to the PFNA group, likely due to superior mechanical stability of the PFBN. The strong mechanical stability of PFBN allows patients to begin early weight-bearing, with mechanical stimulation promoting new bone formation at the fracture site. The bionic triangular stability structure of PFBN helps prevent femoral neck shortening caused by stress during healing. In addition, the final HHS scores in the PFBN group were superior to those in the PFNA group. This may be due to the early weight-bearing capability of PFBN patients, which aids hip joint recovery, and the triangular stability structure of PFBN which minimizes femoral neck shortening during healing, enhancing hip function. This finding is also supported by Cheng et al.'s study.[24] For femoral neck base fractures, PFBN offers superior stress distribution and biological stability compared to PFNA. Its triangular fixation reduces femoral neck shortening seen with PFNA, improving prognosis.

Early internal fixation treatment for intertrochanteric fractures improves patient quality of life and reduces disability and mortality rates.[25] A growing body of evidence indicates that the type of fixation substantially affects postoperative stability of intertrochanteric fractures.[26,27] The PFNA is widely used for treating intertrochanteric fractures, but can lead to complications such as screw cut-out, hip varus deformity, screw withdrawal, femoral neck shortening, and implant failure.[4,28,29] According to the lever-pivot balance theory, the pivot point reconstructed after PFNA fixation is located at the junction of the neck screw and main intramedullary nail, compared to normal anatomical support points.[9] At this location, the moment arm exceeds the resistance arm, placing a larger load on the resistance lever and potentially causing partial or complete loss of the lateral arm's shear resistance structure. The lever point reconstructed by the PFBN support structure is closer to the anatomical support point, shortening the moment arm and restoring the balance between applied pressure and the lever arm. According to Zhang's N-triangle theory of the proximal femur, multiple stable triangular areas are formed by the femoral head, neck, and trabecular bone in the intertrochanteric region.[8] The PFBN is a bionic intramedullary nail designed based on the triangular support stability principle of Zhang's N-triangle theory, which addresses the loss of tension trabecular bone due to fractures.[8] Biomechanical studies have shown that the triangular support internal fixation system aligns better with the biomechanical characteristics of normal femurs, offering more effective intertrochanteric fracture fixation and enhancing stability.[30,31] This study found that patients treated with PFBN began weight-bearing earlier than those treated with PFNA, potentially owing to superior mechanical stability of PFBN. Therefore, surgeons anticipate that patients can begin early weight-bearing and walking, reducing complications such as pulmonary infections and deep vein thrombosis and promoting better hip joint function recovery.

Furthermore, we found surgical time in the PFBN group to be longer than that in the PFNA group, and the amount of intraoperative blood loss was also higher. This is due to the addition of a transverse support screw in the PFBN design, where the extra placement step prolongs the surgical time. Additionally, since PFBN is a novel internal fixation method, the surgical proficiency of operating physicians may be relatively low. This review revealed no significant differences in postoperative complications between PFBN and PFNA. However, a FEA by Chen et al.[32] found that PFBN, compared to PFNA, could better reconstruct lateral wall function, restore physiological mechanical conduction, and improve postoperative stability for A3.3 intertrochanteric femoral fractures, thereby reducing the risk of implant removal and failure. The results of this study contrast with Chen et al.'s findings.[32] The discrepancies may be due to relatively small sample size of this study and the potential for PFBN to offer better stability in intertrochanteric fractures with lateral wall involvement, as suggested by the lever-reconstruction-pivot theory. Further large-scale clinical studies are needed to confirm these findings.

The main limitation to this review is that all included articles are retrospective cohort studies in nature, which are susceptible to selection bias. Differences in surgeon and patient characteristics, such as sex, age, and ethnicity, make heterogeneity among the included studies inevitable. Additionally, the small sample size is a limitation. Therefore, further validation through large-scale prospective, randomized-controlled trials is needed.

In conclusion, both PFBN and PFNA show favorable therapeutic efficacy for treating intertrochanteric fractures in elderly patients. Compared to PFNA, PFBN allows earlier weight-bearing, experience more rapid fracture healing, and shows more successful hip joint recovery.

Data Sharing Statement: The data that support the findings of this study are available from the corresponding author upon reasonable request.

Author Contributions: Analyzed the data, interpreted the results and wrote the manuscript: Y.Q.Z.; Collected the data andconstructed the tables: C.B.L.; Offered suggestions for statistical methods: X.Q.S.; Designed the study and was responsible for revising the manuscript for important intellectual content: Q.M.G. All authors contributed to the article and approved the submitted version.

Conflict of Interest: The authors declared no conflicts of interest with respect to the authorship and/or publication of this article.

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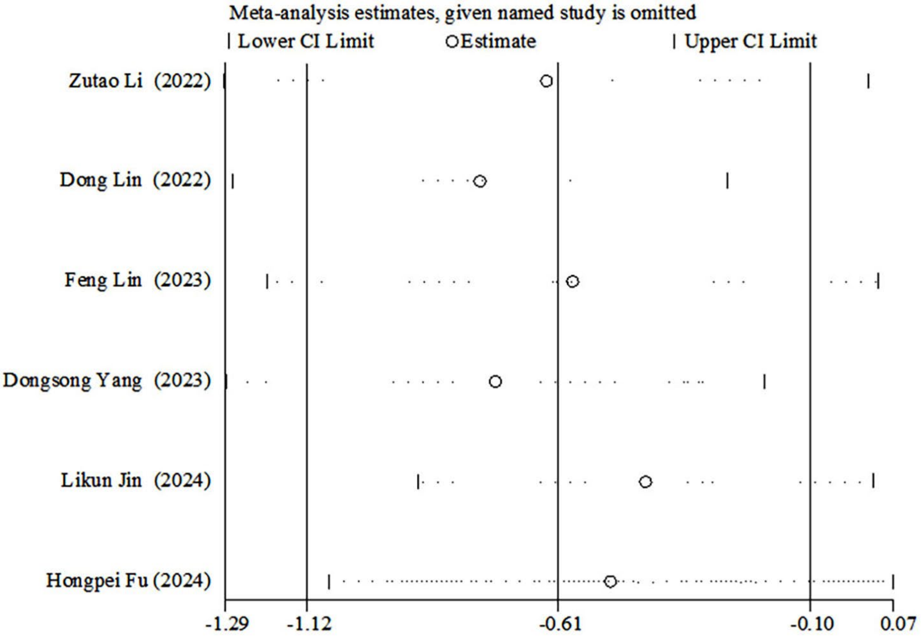
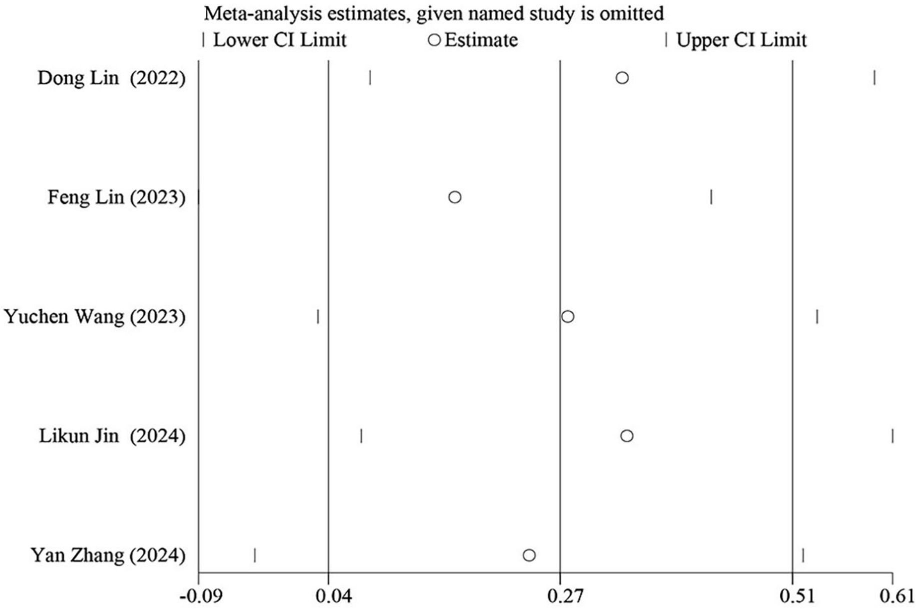
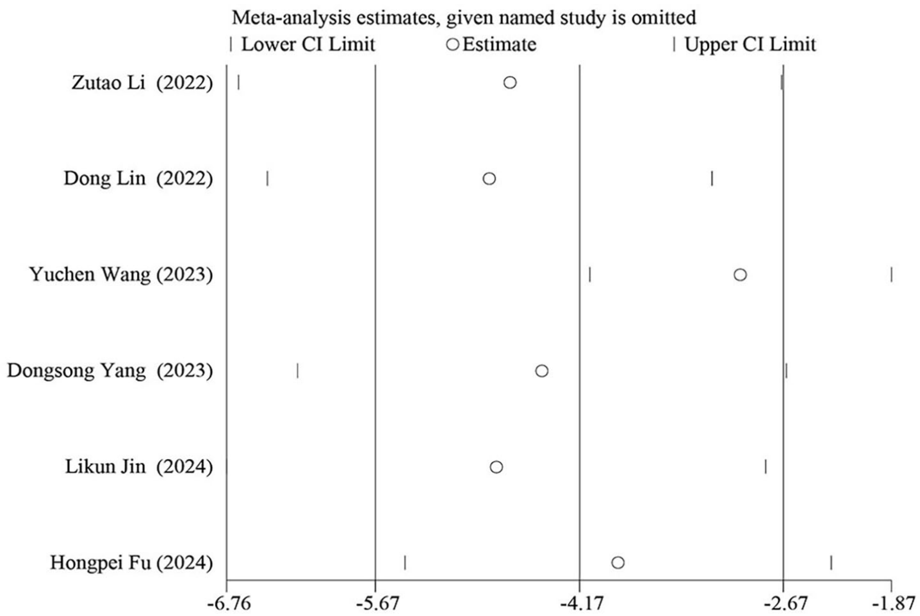


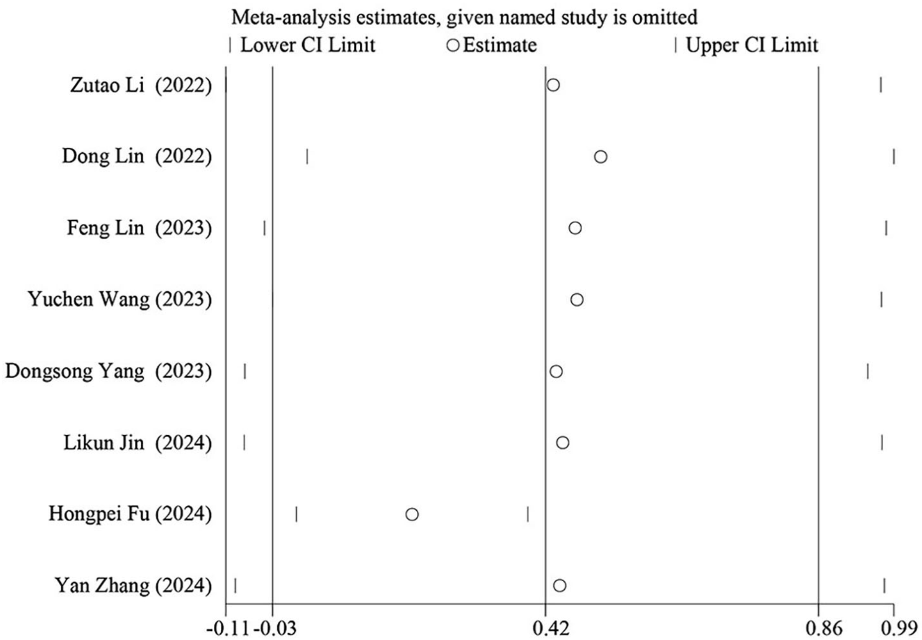
SUPPLEMENTARY FIGURE 1. Fracture healing time.
CI: Confidence interval.



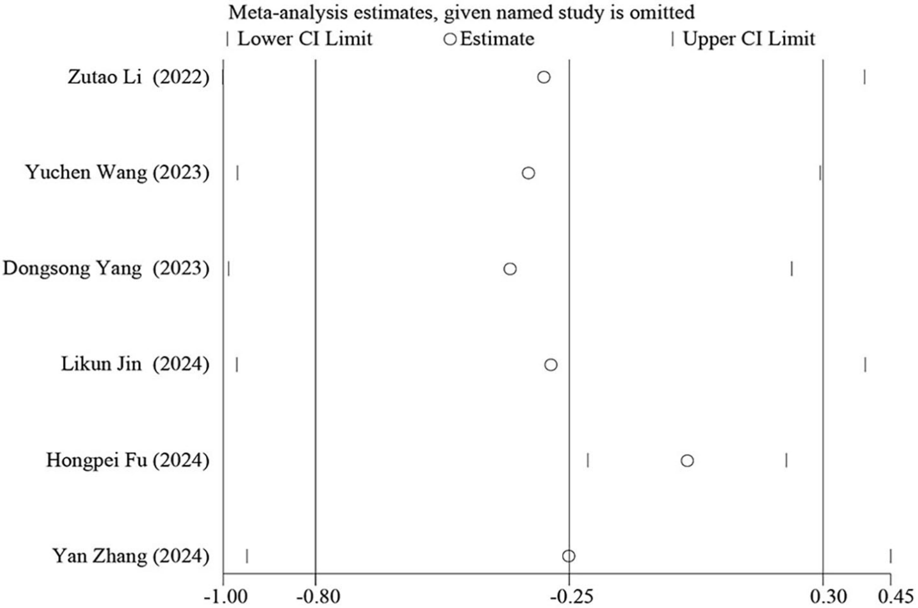
SUPPLEMENTARY FIGURE 2. Final Harris hip score at last follow-up.
CI: Confidence interval.



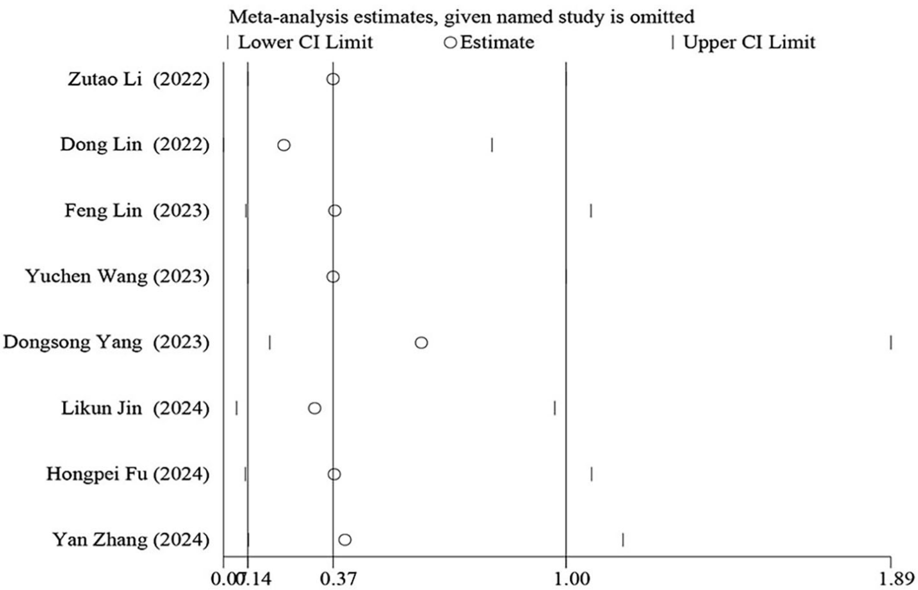
SUPPLEMENTARY FIGURE 3. Opreation time.
CI: Confidence interval.



SUPPLEMENTARY FIGURE 4. Weight-bearing time.
CI: Confidence interval.



SUPPLEMENTARY FIGURE 5. Intraoperative blood loss.
CI: Confidence interval.



SUPPLEMENTARY FIGURE 6. Length of hospital stay.
CI: Confidence interval.