Geriatric Orthopaedic Surgery & Rehabilitation
Volume 15: 1–13

DOI: 10.1177/21514593241273326
journals.sagepub.com/home/gos
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Evaluation of Post-Operative Outcomes of Femoral Neck Fracture Interventions: A Systematic Review

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Abstract

Introduction: Femoral neck fractures (FNF) represent a significant challenge in orthopedic practice, demanding prompt intervention to restore function and mobility in affected individuals. Numerous surgical interventions have been developed to address these fractures, including internal fixation with devices such as the Femoral Neck System (FNS, DePuy Synthes, Inc., West Chester, PA, USA). However, the optimal fixation system remains unclear. Understanding the postoperative outcomes associated with these interventions is crucial for optimizing patient care and informing treatment decisions. **Significance:** This PRISMA-compliant systematic literature review evaluates the efficacy and safety of the Femoral Neck System relative to other operative treatment options. Clinical and safety outcomes included mortality, perioperative complications, postoperative complications at 1 year, and reoperation. **Results:** A total of 117 studies with 68,567 patients with FNF treated with internal fixation were identified. Of these, thirteen included FNS as a treatment arm (1078 patients). Due to heterogeneity in study designs and populations, only the eleven studies that directly compared FNS to other operative treatments, and 2 non-comparative studies that treated with FNS were included in the systematic review. Seven of the eleven included studies had high risk of bias, 2 had moderate risk of bias, and 2 had low risk of bias. FNS groups had similar or significantly lower incidences of postoperative complications, reoperations, and mortality compared to cannulated screw, cancellous screw, or dynamic or sliding hip screw groups in all studies. **Conclusion:** FNS can be a safe and effective operative treatment option for FNF. Safety outcomes and reoperation rates are comparable between patients treated with FNS and patients treated with cannulated screws, cancellous screws, and dynamic or sliding hips screws. Future prospective, controlled studies are needed to confirm the safety and efficacy of FNS relative to other operative treatment options.

Keywords

femoral neck fracture, femoral neck system, hip fracture, dynamic screws

Submitted 22 August 2023. Revised 17 June 2024. Accepted 8 July 2024

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Introduction

Femoral neck fractures (FNF), the most common hip fracture,[1] are frequently treated with internal fixation, but complications frequently arise, which may require reoperation.[2] Recently, a new fixation device, Femoral Neck System (FNS, DePuy Synthes, Inc., West Chester, PA, USA) was launched for treatment of femoral neck fractures, including basilar, transcervical, and subcapital fractures, in adults and adolescents (age 12-21 years) in which the growth plates have fused or will not be crossed (Figure 1). FNS was developed to reduce complications and reoperations by increasing construct stability, reducing surgical invasiveness, and reducing the risk of lateral implant protrusion.[3] The FNS design compensated for 15 mm of femoral neck shortening without lateral protrusion by a telescoping mechanism.[3] Moreover, a single insertion handle allows for placement of the central bolt as well as the antirotation screw to reduce procedural complexity and enhance operational efficiency.[3] The bolt is currently available in units of 5 mm and a technical note has reported a modified technique for improved control of the depth of the bolt.[4]

Mechanical testing of FNS with standardized foam models has indicated up to 40% increased rotational stability compared to a sliding hip screw (SHS), and a minimum of 150% more rotational stability compared to a 3 cannulated screw.[5,6] A biomechanical study in a cadaveric model found that FNS had comparable stability to dynamic hip screws paired with antirotation screws or blades and superior stability compared to 3 cannulated screws for treating femoral neck fractures.[7] However, the relative safety and efficacy of FNS compared to other treatment options remain undetermined. Here, we report the results of a systematic literature review to evaluate safety and efficacy outcomes associated with FNS relative to traditional operative treatment options in femoral neck fractures resulting from any mechanism of injury.

Methods

Literature Search and Study Selection

This study adheres to PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) guidelines.[8] The PRISMA checklist associated with this systematic review can be found in Supplemental Files 1 and 2. A protocol was prepared based on the PROSPERO protocol guidelines. The review was not registered. Searches of PubMed were completed using the Application Program Interface (API) in the AutoLit platform (Nested Knowledge, nested-knowledge.com). All study metadata and abstracts from the search results were also obtained via API. Searches of Cochrane Library and Embase databases were completed through their respective web interfaces and the results were uploaded to the AutoLit platform.

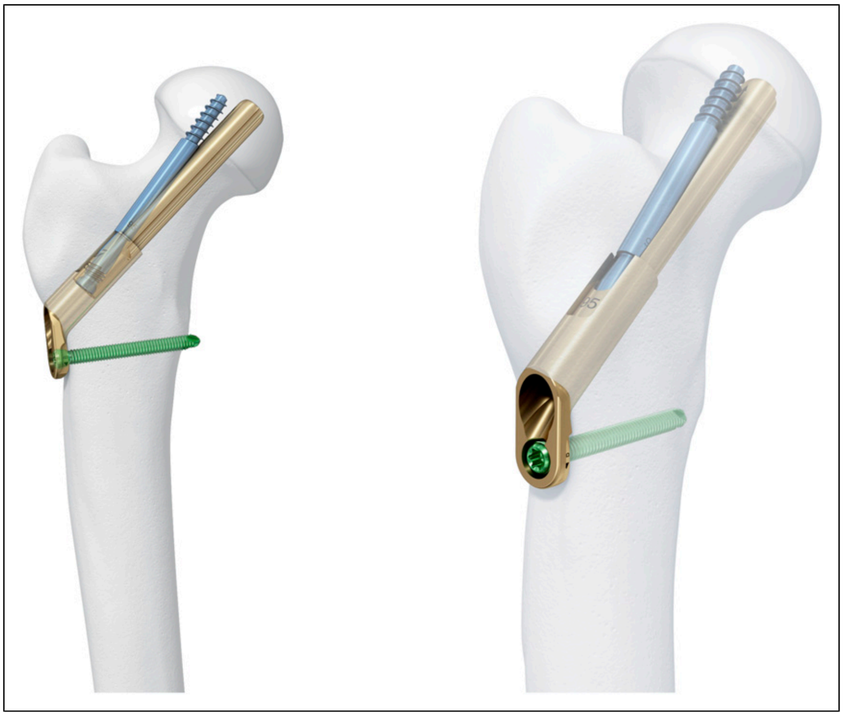

Figure 1. Three dimensional models of the FNS device. Used with permission.

Searches were restricted to studies published after January 1, 2012 to capture the previous decade of comparative treatments and cover the date that FNS came on the market in 2017. Search terms included the phrases "femoral neck fracture", "femoral neck system", "sliding hip screw", "cannulated screw", and "internal fixation". The full search strings are available in Supplemental Table 1.

Identified studies were evaluated for inclusion in the systematic review. Study inclusion criteria included those reporting adult patients with femoral neck fracture treated with FNS. All mechanisms of injury were included. Exclusion criteria were studies that did not report patients treated with FNS, studies that did not report the outcomes of interest, studies that did not separate patient outcomes by intervention, studies with less than 5 patients, studies that did not relate to femoral neck fracture, studies not reporting interventions or outcomes of interest, and studies reporting on a subpopulation that could introduce bias, including studies that focused on patients with cancer, HIV, or Parkinson's disease. *In vivo/ in vitro* studies, symposium/conferences, qualitative review articles, letters of correspondence, in silico study/ mathematical models, guideline articles, technical notes, editorial/opinion articles, meta-analyses or systematic reviews, secondary analyses, protocols, studies not written in English, or interim analyses were also excluded. The reference lists of identified articles were also screened for potentially relevant papers. Each study was screened by a single investigator.

Data Extraction

Data was extracted by a single investigator for each study and reviewed by 2 independent investigators. Patient characteristics included age and fracture stability (Garden classification). Procedure characteristics included length of operation, intraoperative blood loss, and length of hospital stay. Methods for measuring blood loss vary widely, potentially introducing heterogeneity into the data. Intraoperative blood loss was extracted as reported in the study. Clinical and safety outcomes included mortality, perioperative complications (deep vein thrombosis [DVT] and perioperative surgical site infection), postoperative complications at 1 year (avascular necrosis [AVN] of the femoral head, non-union, internal fixture loosening, postoperative surgical site infection, hematoma, iatrogenic fracture, and femoral neck shortening), and reoperation (unspecified, implant removal, or conversion to another treatment).

Risk of Bias

Risk of bias (RoB) was assessed for comparative studies using the Newcastle-Ottawa Scale.[9] Criteria for rating a study as low, moderate, or high risk of bias were made based on the decision rules described by Sharmin et al,[10] outlined in Supplemental Table 2. The RoB was completed independently by 2 reviewers with any disagreements adjudicated by a third reviewer.

Statistical Analysis

Due to heterogeneity in data and the limited number of multi-armed studies available that distinguished between patients with acute and delayed instrumentation, inferential statistics were not performed, and data are expressed as descriptive statistics only. Statistics are reported as counts and percentages, median (interquartile range (IQR)), or mean ± standard deviation (SD).

Results

Literature Search Results

Our searches identified 1674 individual studies. Of the identified studies, 1394 were excluded based on title and abstract review (see PRISMA flowchart in Figure 2). The remaining 271 articles underwent full-text review. Four articles were identified through expert recommendation, which also underwent full-text review. Nine articles did not have full texts available, and 259 articles were excluded for other reasons, while 108 studies reported a comparable intervention but did not report patients treated with FNS (see PRISMA flowchart in Figure 2). Due to heterogeneity in study designs and populations, only the 13 studies that included patients treated with FNS were included in the systematic review.[11-23] Results from all 117 studies reporting either FNS or a comparable intervention are summarized in Supplemental Tables 3-6. Of the 13 studies reporting FNS, all were retrospective cohort studies.[11-23] Three studies compared dynamic or sliding hip screws or cannulated screws to FNS,[16,17,20] 2 studies had a single intervention of FNS with no comparator,[12,18] 1 study compared dynamic or sliding hip screws or cancellous screws to FNS,[21] 1 study compared dynamic or sliding hip screws to FNS,[16] and 6 studies compared cannulated screws to FNS.[13-15,19,22,23] Two studies were found to have low risk of bias,[19,23] 2 had moderate risk of bias,[13,16] and 7 had high risk of bias.[11,14,15,17,20-22] The 2 non-comparative studies were not included in the risk of bias (Supplemental Table 7)

FNS vs Cannulated Screws

Study Characteristics. Seven studies compared FNS against cannulated screws.[13-15,19,20,22,23] Of these, Vazquez et al[20] compared a third treatment such that head-to-head comparisons between FNS and cannulated screws were not made. Nibe et al[15] and Zhang et al[22] restricted study patients to ≥65 years old and Vazquez et al[20] reported outcomes in patients ≥75 years old. Hu et al restricted to

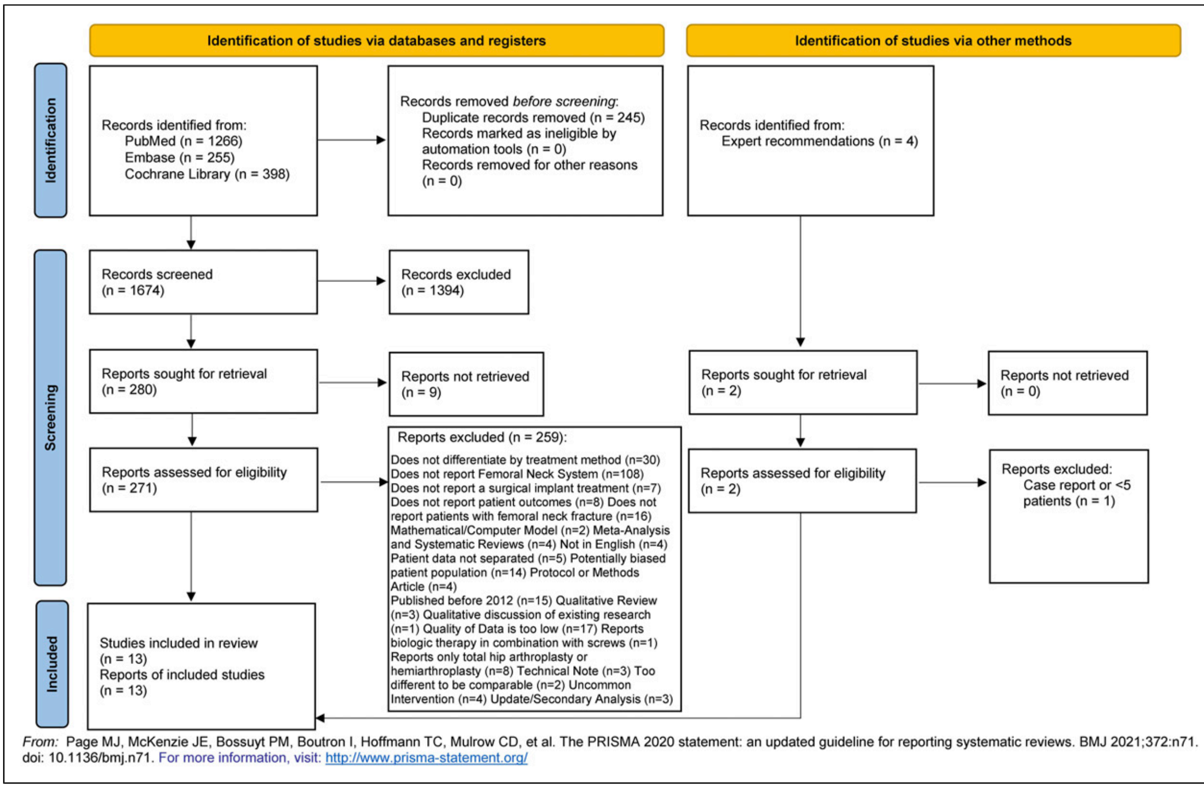

Figure 2. PRISMA study selection flowchart.

patients under 60 years old.[14] Zhang et al[22] restricted their study to patients with AO31-B type fractures, which include Garden Type II, III, and IV, Zhou et al[23] reported only patients with Pauwels Type III fractures, and Vazquez et al[20] restricted their study to patients with Garden Type I and II fractures. Two studies did not apply fracture type or age-based selection criteria, but excluded pathological fractures.[13,19]

Three studies did not specify mechanism of injury.[14,19,20] In He et al, the majority of fractures were caused by falls in both groups (63.6% [21/33] in patients treated with FNS and 69.4% [25/36] in patients treated with cannulated screws).[13] In Nibe et al, the majority of fractures were caused by low-energy falls in both groups (88.0% [22/25] in patients treated with FNS and 81.5% [22/27] in patients treated with cannulated screws). The remaining fractures were caused by traffic accidents (8.0% [2/25] in patients treated with FNS only), other high-energy injuries (3.7% [1/27] in patients treated with cannulated screws only) or unknown causes (4.0% [1/25] in patients treated with FNS and 14.8% [4/27] in patients treated with cannulated screws).[15] In Zhou et al, fractures were caused by traffic accidents or falls and pathological fractures were excluded.[23]

Two studies had low risk of bias,[19,23] 1 had moderate risk of bias,[13] and 4 had high risk of bias.[14,15,20,22] Common sources of risk of bias were selection bias, lack of comparability between groups, and short follow-up. A summary of risk of bias assessments can be found in Supplemental Table 7.

Patient Baseline Characteristics. Patient baseline characteristics are presented in Supplemental Table 3. Across studies, the average age ranged from 47.6 ± 10.3[13] to 85.0 ± 6.6[20] for patients with cannulated screws, and from 50.5 ± 8.5[14] to 86.1 ± 4.6[20] for patients with FNS. No studies reported statistically significant differences in age between groups. Only Nibe et al[15] and Zhou et al[23] did not present Garden classification. Except for Vazquez et al,[20] in which most injuries were Type I, most injuries were Type II or above. No study reported significant differences for Garden classification between groups. Most studies had follow-up periods >12 months, but Vazquez et al[20] had follow-ups from 1-6 months and Zhou et al[23] had follow-ups from 10-22 months. The longest follow-up period was a range of 14-24 months.[19]

Procedure Characteristics. Procedure characteristics are presented in Table 1. The average length of operation ranged from 40.9 ± 5.2[23] to 76.8 ± 13.1[22] minutes for cannulated screws, and from 42.0 ± 13.0[15] to 79.8 ± 26.4[14] for FNS. Compared to cannulated screws, 2 studies reported lower mean operation time in patients treated with FNS,[15,22] but

1 study reported significantly higher mean operation time (Table 1).[14] Four studies reported intraoperative blood loss, ranging from 23.7 ± 28.1[14] to 47.3 ± 9.3 mL[19] for cannulated screws and from 36.0 ± 25.0[15] to 99.7 ± 52.7 mL[23] for FNS. Two studies reported significantly higher intraoperative blood loss in patients treated with FNS compared to cannulated screws, but both studies also reported that patients treated with FNS had lower incidence of complications, indicating that the difference in blood loss may not be clinically significant.[14,23] All but Hu et al[14] and Nibe et al[15] reported length of hospital stay. No studies reported significant differences in length of hospital stay between patients treated with FNS and cannulated screws. Studies that restricted study patients to ≥65 years old found that FNS had significantly lower operation time and no significant differences in intraoperative blood loss or hospital stay compared to cannulated screws.[15,20,22]

Patient Outcomes. Patient outcomes are presented in Table 2. No significant differences between FNS and cannulated screws were reported for non-union events,[13-15,19] loosening or failure of the internal fixture,[13,15,19] avascular necrosis,[14,19,23] deep vein thrombosis,[19,23] or mortality.[20,22] Hu et al[14] found that significantly more cannulated screw patients experienced femoral neck shortening than FNS patients (9/24 vs 2/20, $P = 0.04$), but Zhang et al[22] found no significant difference between groups (5/36 vs 2/33, $P = 0.28$). He et al[13] found that 8.3% (3/36) of cannulated screw patients and 3.0% (1/33) of FNS patients experienced femoral neck shortening, but did not report a statistical analysis. Nibe et al[15] found significantly more reoperations for cannulated screw patients than FNS patients (6/21 vs 0/25, $P = 0.23$). Three other studies reported incidence of reoperation,[20,22,23] but no other study reported a statistical analysis. Studies that restricted study patients to ≥65 years old found that FNS had significantly lower incidence of reoperation compared to cannulated screws, with no other significant differences.[15,20,22]

FNS vs Dynamic or Sliding Hip Screw

Study Characteristics. Four studies compared FNS with dynamic or sliding hip screws.[16,17,20,21] Of these, Vazquez et al[20] and Xu et al[21] compared a third treatment such that head-to-head comparisons between FNS and cannulated screws were not made. Three studies applied age-related inclusion criteria: Vazquez et al[20] (≥75 years old), Schuetze et al[17] (≥50 years old) and Xu et al[21] (<65 years old). Vazquez et al[20] and Xu et al[21] restricted their studies to patients with Garden Type I and II fractures. Niemann et al[16] and Schuetze et al[17] excluded pathological fractures. No studies specified mechanism of injury. One study had moderate risk of bias[16] and 3 studies had high risk of bias.[17,20,21] Common sources of risk of bias included selection bias, failure to account for imbalances in important patient characteristics between cohorts, short follow-up, and failure to properly adjust analyses for imbalances in follow-up periods between cohorts. A summary of risk of bias assessments can be found in Supplemental Table 7.

Patient Baseline Characteristics. Across studies, the average age ranged from 60.5 ± 17[16] to 83.4 ± 7.3 years[20] for patients with dynamic or sliding hip screw, and from 60.7 ± 15.2[21] to 86.1 ± 4.6 years[21] for FNS patients. No study found significant differences in age between groups. Likewise, no study reported significant differences in Garden classification between groups. Follow-up periods ranged from 7.4 ± 3.4 days[16] to 12-16 months.[21] No study reported significant differences for follow-up periods between groups (Supplemental Table 3).

Procedure Characteristics. The average duration of operation ranged from 54.7 ± 17.4[17] to 91.7 ± 24.0 minutes[16] for dynamic or sliding hip screw patients, and from 36.3 ± 11.6[17] to 54.0 ± 26.1 minutes[16] for FNS patients. In each study, FNS had significantly shorter operation time than dynamic or sliding hip screws.[16,17,20,21] Only Xu et al[21] reported on intraoperative blood loss; dynamic or sliding hip screws operations had significantly more blood loss than FNS (median, range: 50, 30-50 vs median, range: 30, 20-50; $P < 0.01$). Length of hospital stay ranged from 3-6[21] to 12.4 ± 5.3 days[20] for dynamic or sliding hip screws and from 2-4[21] to 10.3 ± 6.0 days[20] for FNS. Only Schuetze et al[17] and Xu et al[21] found significant differences for length of hospital stay between groups; in both cases, FNS patient stays were significantly shorter than dynamic or sliding hip screw patient stays (Table 1).

Patient Outcomes. No study reported incidence of non-union. No significant differences between FNS and dynamic or sliding hip screws were reported for loosening or failure of the internal fixure,[17,21] avascular necrosis,[17,21] deep vein thrombosis,[21] femoral neck shortening,[16,17,21] hematoma or surgical site infection,[17] reoperation,[17,20] or mortality[17,20] (Table 2).

FNS vs Other Comparators

Xu et al[21] compared FNS with cancellous screws. The study excluded patients >65 years old who had Garden Type III or IV fractures or pathological fractures and did not specify mechanisms of injury. The study had a high risk of bias, primarily due to selection bias, failure to account for imbalances in important patient characteristics between cohorts, short follow-up, and failure to properly adjust analyses for imbalances in follow-up periods between cohorts. Xu et al[21] used linear regression that included a

Table 1. Procedure Characteristics.

Study	Intervention	N	Length of Operation (minutes)	*P* value	Intraoperative Blood Loss (mL)	*P* value	Length of Hospital Stay (days)	*P* value	Reported Conclusions
He, 2021[13]	Cannulated screw	36	56.1 ± 12.5	0.062[a]	--	--	4.8 ± 1.6	0.410[a]	The interventions had no significant differences in procedural characteristics
	FNS (DePuy synthes)	33	49.9 ± 14.5		--		5.1 ± 1.9		
Hu, 2021[14]	Cannulated screw	24	64.6 ± 18.6	0.031[a]	23.7±28.1	<0.001[a]	--	--	FNS had a higher length of operation and intraoperative blood loss
	FNS (DePuy synthes)	20	79.8 ± 26.4		69.5±50.5		--		
Nibe, 2021[15]	Cannulated screw	27	53 ± 21	0.032[a]	41±40	0.58[a]	--	--	FNS had a lower length of operation and intraoperative blood loss
	FNS (DePuy synthes)	25	42 ± 13		36±25		--		
Tang, 2021[19]	Cannulated screw	45	42 ± 11.9	0.590[b]	47.3±9.3	0.284[b]	4.8 ± 1.4	0.113[b]	The interventions had no significant differences in procedural characteristics
	FNS (DePuy synthes)	47	52.4 ± 11.0		50.6 ± 10.6		5.5 ± 1.3		
Vazquez, 2021[20]	Cannulated screw	32	66.9 ± 25.4	<0.001[c]	--	--	12.2 ± 6.2	0.131[d]	FNS had a lower length of operation
	Dynamic or sliding hip screw	16	70.7 ± 20.0		--		12.4 ± 5.3		
	FNS (DePuy synthes)	15	43.3 ± 10.1		--		10.3 ± 6.0		
Zhang, 2022[22]	Cannulated screw	36	76.81 ± 13.10	0.000[a]	--	--	8.5 ± 1.95	0.082[a]	FNS had a lower length of operation
	FNS (DePuy synthes)	33	60.00 ± 12.44		--		7.57 ± 2.39		
Zhou, 2021[23]	Cannulated screw	51	40.9 ± 5.2	0.122[a]	30.27 ± 9.04	<0.001[a]	5.3 ± 1.5	0.133[a]	FNS had a higher intraoperative blood loss
	FNS (DePuy synthes)	30	42.8 ± 4.7		99.73 ± 52.73		5.1 ± 1.3		
Niemann, 2022[16]	Dynamic or sliding hip screw	19	91.68 ± 23.96	<0.01[e]	--	--	7.35 ± 3.43	0.94[e]	FNS had a lower length of operation
	FNS (DePuy synthes)	12	54 ± 26.1		--		8 ± 5.27		
Schuetze, 2022[17]	Dynamic or sliding hip screw	108	54.7 ± 17.4	<0.05[f]	--	--	11.3 ± 6.8	<0.05[f]	FNS had a lower length of operation and length of hospital stay
	FNS (DePuy synthes)	113	36.3 ± 11.6		--		8.9 ± 4.3		
Xu, 2022[21]	Cancellous screw	51	49 (38-61)	<0.001[d]	30 (20-45)	<0.001[d]	3 (2-4)	<0.001[d]	FNS had a lower length of operation, intraoperative blood loss, and length of hospital stay
	Dynamic or sliding hip screw	52	72 (55-88.75)		50 (30-50)		3.5 (3-6)		
	FNS (DePuy synthes)	54	45 (40-59)		30 (20-50)		2 (2-4)		
Cintean, 2021[11]	FNS (DePuy synthes)	29	--	--	--	--	9.8 ± 3.8	<0.001[e]	FNS had a lower length of hospital stay
	Hemiarthroplasty	34	--		--		15.1 ± 5.1		
Non-comparative studies									
Davidson, 2022[12]	FNS (DePuy synthes)	102	44 ± 14	--	51 ± 47	--	5.7 ± 3.9	--	No comparison between interventions
Stassen, 2021[18]	FNS (DePuy synthes)	34	Mean: 33 (95% CI: 29.3-36.9)	--	Mean: 34 (95% CI: 24.7-44.6)	--	4 ± 2.8	--	No comparison between interventions

Data are expressed as mean ± SD or median (IQR). "--" indicates no data reported.
[a]Independent-samples *t* test.
[b]Analysis unclear (either Mann-Whitney U test or independent-samples *t* test).
[c]Linear regression.
[d]Kruskal-Wallis test.
[e]Mann-Whitney U test.
[f]Statistical methods not clearly reported.

third procedure such that head-to-head comparisons were not made, median operation time, blood loss, and length of hospital stay were lower for FNS than cancellous screws (Table 1). No differences in patient outcomes were reported between the FNS and cancellous screws (Table 2).

Cintean et al[11] compared FNS with hemiarthroplasty. The study did not apply age-based selection criteria and did not specify mechanisms of injury. The study had high risk of bias due to lack of comparability between the groups, short follow-up, and loss of patients to follow-up. There were no significant differences between groups for age, Garden classification, or follow-up period (Supplemental Table 3). Cintean et al[11] found that length of hospital stay was significantly shorter for FNS than hemiarthroplasty (Table 1), but did not find any differences in patient outcomes (Table 2).

Non-Comparative Studies

There were 2 non-comparative studies of FNS.[12,18] Davidson et al[12] excluded cases with pathological fractures and Stassen et al[18] excluded patients with polytrauma. Neither study applied age-related selection criteria or specified mechanism of injury. The average age in both studies was 63 years. In both studies, more than half of the fractures were at or below Garden Type II. The mean follow-up periods were 7[12] and 6 months[18] (Supplemental Table 3). Mean length of operations were 44[12] and 33 minutes.[18] Mean intraoperative blood-loss was 51[12] and 34 mL.[18] Average length of hospital stay was 5.7 ± 3.9[12] and 4.0 ± 2.8 days[18] (Table 1). Davidson et al[12] reported 1.0% (1/102) non-union events and 1.0% (1/102) patients with loosening/failure of internal fixtures, while Stassen et al[18] did not report on non-union events and reported 5.9% (2/34) patients with loosening or failure of internal fixtures. Avascular necrosis was reported in 2.9% (3/102)[12] and 11.8% (4/34)[18] cases. Davidson et al[12] reported that 8.8% (9/102) of cases were converted to hemiarthroplasty while Stassen et al[18] reported that 17.6% (6/34) were converted with another 5.9% (2/34) implants removed. Neither study reported any deaths[12,18] (Table 2).

Discussion

The results of our systematic literature review suggest that FNS can be safely and effectively used to treat FNF compared to other operative treatments. The majority of studies reported no significant difference in patient outcomes including non-union,[11,15,19] change in internal fixture loosening/failure,[17,19,21,22] postoperative complications,[11,16,17,23] reoperation,[11] and mortality,[11,17,20] with respect to the comparator device. Studies identified significantly better outcomes associated with FNS compared to cannulated screws, for reduced femoral neck shortening length and incidence,[14] reduced incidence of reoperation,[15] and lower incidence of implant removal.[22] One study, a systematic review by Zhou et al, reported that FNS were associated with a significantly lower incidence of overall complications compared to those treated with cannulated screws.[23]

The relative incidences of complications and mortality found in the thirteen studies reporting FNS are also comparable or lower than the incidences reported for comparators in the 104 comparator-only studies, supporting the conclusion that FNS is comparable to similar operative treatments. The 2 non-comparative studies found similar results when using FNS. These conclusions are also in line with previous systematic reviews comparing operative treatments, which have found that dynamic and sliding hip screws and cannulated cancellous screws are largely comparable with respect to safety outcomes.[24,25] Recently, another case series was published reporting outcomes in 12 patients after treatment with FNS, which found higher rates of complications compared to previously reported incidences for comparators.[26] A larger case series recently reported a high incidence of femoral neck shortening in patients treated with FNS, with no effect on fracture healing.[27] However, a recent comparative study found no difference in incidence of complications between patients treated for femoral neck fractures with FNS or cancellous screws, while patients treated with FNS had significantly better joint function,[28] and another comparative study found that FNS was more effective compared to a dynamic compression locking plate system.[29] Future comparative studies are need to confirm the relative incidence of complications in patients treated with FNS and address considerations such as long-term stability and mobility, which may have different priorities in different patient populations, depending on age and activity.

Factors other than implant choice impact revision and conversion rates and incidence of AVN, potentially explaining the low effect size between groups. The use of computed tomography scans or magnetic resonance imagery, rather than basic X-rays, may improve diagnostic accuracy by allowing physicians to visualize the fracture more clearly. Different imaging methods and protocols for when patients received imaging may have contributed to heterogeneity in reported incidence AVN between studies and among patients in individual studies. Better visualization may lead to more accurate classification of fracture displacement, informing treatment decisions.[30-32] Stable internal fixation is key to prevent non-union and allow for positive functional outcomes, especially in younger patients, who have higher functional demands[33] and a high rate reoperation and conversion to total hip arthroplasty.[34] Young patients with Pauwels Type III FNF specifically have increased likelihood of loss of reduction and non-union.[35] The use of adjunctive implants is currently

Table 2. Patient Outcomes.

Study	Intervention	N	Non-union	Internal Fixture Loosening/ Failure	Other Postoperative Complications	Reoperation	Mortality	*P* values	Reported Conclusions
He, 2021[13]	Cannulated screw	36	5.6% (2/36)	8.3% (3/36)	Femoral neck shortening: 8.3% (3/36)	--	--	--	FNS had a lower incidence of overall complications (combining non-union, nail retreat, femoral neck shortening, and internal fixation cutout)
	FNS (DePuy synthes)	33	0.0% (0/33)	3.0% (1/33)	Femoral neck shortening: 3.0% (1/33)	--	--		
Hu, 2021[14]	Cannulated screw	24	12.5% (3/24), P = 0.795	--	AVN: 12.5% (3/24), Femoral neck shortening: 4.54±2.75 mm 37.5% (9/24)	--	--	AVN: P = 0.389[a] Femoral neck shortening length: P = 0.005[b]	FNS had a lower degree of femoral neck shortening and a lower incidence femoral neck shortening, but no difference in incidence of non-union or AVN.
	FNS (DePuy synthes)	20	10.0% (2/20)	--	AVN: 5.0% (1/20) Femoral neck shortening: 2.40±1.81 mm 10.0% (2/20)	--	--	Femoral neck shortening incidence: P = 0.036[a]	
Nibe, 2021[15]	Cannulated screw	27	18.5% (5/27)	7.4% (2/27)	--	Overall: 28.6% (6/21) Conversion to HA: 11.1% (3/27) Implant removal: 11.1% (3/27)	--	Non-union: P = 0.052[c] Overall reoperation: P = 0.023[c]	FNS had a significantly lower incidence of reoperation
	FNS (DePuy synthes)	25	0.0% (0/25)	--	--	0.0% (0/25)	--		
Tang, 2021[19]	Cannulated screw	45	8.9% (4/45)	11.1% (5/45)	AVN: 6.7% (3/45) DVT: 0.0% (0/45)	--	--	Non-union: P = 0.430[a]	The interventions had no significant differences in patient outcomes
	FNS (DePuy synthes)	47	4.3% (2/47)	6.4% (3/47)	AVN: 2.1% (1/47) DVT: 0.0% (0/47)	--	--	Internal fixture loosening/ failure: P = 0.481[a] AVN: P = 0.356[a]	
Vazquez, 2021[20]	Cannulated screw	32	--	--		3.1% (1/32)	9.4% (3/32)	Mortality: P = 0.585[c]	The interventions had no significant differences in patient outcomes
	Dynamic or sliding hip screw	16	--	--	--	0.0% (0/16)	12.5% (2/16)		
	FNS (DePuy synthes)	15	--	--	--	0.0% (0/15)	0.0% (0/15)		

(continued)

Table 2. (continued)

Study	Intervention	N	Non-union	Internal Fixture Loosening/ Failure	Other Postoperative Complications	Reoperation	Mortality	*P* values	Reported Conclusions
Zhang, 2022[22]	Cannulated screw	36	--	--	Femoral neck shortening: 13.89% (5/36)	Implant removal: 13.89% (5/36)	0.0% (0/36)	Femoral neck shortening: *P* = 0.282[a]	FNS had a lower incidence of implant removal
	FNS (DePuy synthes)	33	--	--	Femoral neck shortening: 6.06% (2/33)	Implant removal: 0.0% (0/33)	0.0% (0/33)	Implant removal: *P* = 0.026[a]	
Zhou, 2021[23]	Cannulated screw	51	--	--	AVN: 0.0% (1/51) DVT: 0.0% (0/51)	Conversion to HA: 3.9% (2/51)	--	--	FNS had a lower incidence of overall complications
	FNS (DePuy synthes)	30	--	--	AVN: 0.0% (0/30) DVT: 0.0% (0/30)	Conversion to HA: 3.3% (1/30)	--		
Niemann, 2022[16]	Dynamic or sliding hip screw	19	--	--	AVN: 0.0% (0/19) Femoral neck shortening: 0.0% (0/19) Femoral neck shortening: 0.0% (0/12)	--	--	--	The interventions had no significant differences in patient outcomes
	FNS (DePuy synthes)	12	--	--	AVN: 0.0% (0/12)	--	--	--	
Schuetze, 2022[17]	Dynamic or sliding hip screw	108	--	10.2% (11/108)	Femoral neck shortening: 4.8±2.1 mm 27.7% (30/108) Hematoma: 5.6% (6/108) Surgical site infection: 2.8% (3/108)	Conversion to THA: 8.3% (9/108) Implant removal: 1.9% (2/108)	0.9% (1/108)	Failure, hematoma, or infection: *P* = 0.479[d] Femoral neck shortening: 0.455[d] Mortality: >0.05[d]	The interventions had no significant differences in patient outcomes
	FNS (DePuy synthes)	113	--	12.4% (14/113)	Femoral neck shortening: 5.3±1.9 mm 27.4% (31/113) Hematoma: 0.9% (1/113) Surgical site infection: 0.0% (0/113)	Conversion to THA: 11.5% (13/113) Implant removal: 0.9% (1/113)	3.5% (4/113)		

(continued)

Table 2. (continued)

Study	Intervention	N	Non-union	Internal Fixture Loosening/ Failure	Other Postoperative Complications	Reoperation	Mortality	*P* values	Reported Conclusions
Xu, 2022[21]	Cancellous screw	51	--	3.9% (2/51)	AVN: 0.0% (0/51) DVT: 0.0% (0/51) Femoral neck shortening: 1.9 mm (0.2-3.5)	--	--	Internal fixture loosening/ failure: P = 1.000[c] Femoral neck shortening: P = 0.452[e]	The interventions had no significant differences in patient outcomes
	Dynamic or sliding hip screw	52	--	3.8% (2/52)	AVN: 0.0% (0/52) DVT: 0.0% (0/52) Femoral neck shortening: 2.0 mm (0.2-4.8)	--	--		
	FNS (DePuy synthes)	54	--	5.6% (3/54)	AVN: 0.0% (0/54) DVT: 0.0% (0/54) Femoral neck shortening: 2.2 mm (0.4-4.1)	--	--		
Cintean, 2021[11]	FNS (DePuy synthes)	29	--	--	AVN: 0.0% (0/21) Femoral neck shortening: 3.3±4.5 mm, 100.0% (21/21)	Overall: 13.8% (4/29) Conversion to hemiarthroplasty: 10.3% (3/29) Removal of implant: 3.4% (1/29)	6.9% (2/29)	Mortality: P = 0.663[c]	The interventions had no significant difference in patient outcomes
	Hemiarthroplasty	34	--	--	--	Overall: 8.8% (3/34) Conversion to HA: 2.9% (1/34)	8.8% (3/34)		
Non-comparative studies									
Davidson, 2022[12]	FNS (DePuy synthes)	102	1.0% (1/102)	1.0% (1/102)	AVN: 2.9% (3/102)	Conversion to THA: 8.8% (9/102)	0.0% (0/102)	--	No comparison between interventions
Stassen, 2021[18]	FNS (DePuy synthes)	34	--	5.9% (2/34)	AVN: 11.8% (4/34)	Conversion to THA: 17.6% (6/34) Implant removal: 5.9% (2/34)	0.0% (0/34)	--	No comparison between interventions

Data are expressed as mean ± SD, median (IQR), or % (n) unless otherwise indicated. "--" indicates no data reported.
AVN = avascular necrosis; DVT = deep vein thrombosis; FNS = Femoral Neck System; HA = hip arthroplasty; THA = total hip arthroplasty.
[a]Chi-squared test of independence.
[b]Independent-samples *t*-test.
[c]Fisher's exact test.
[d]Statistical methods not clearly reported.
[e]Kruskal-Wallis test.

uncommon, but combining established implants with other stabilizing measures may provide additional stability and improve patient functional outcomes, particularly in young patients with displaced fractures.[36-39]

A simplified classification scheme of stable vs unstable may also improve treatment decision-making. Current guidelines suggest classifying fractures as non-displaced (Garden Type I or II) or displaced (Garden Type III or IV).[40] Both non-displaced and displaced fractures may be treated with internal fixation in younger patients,[33,41] but currently only non-displaced fractures are recommended to be treated with internal fixation in older patients.[40] However, Vazquez et al suggest that using implants, including FNS, cannulated screws, or dynamic or sliding hip screws, to treat displaced fractures in older patients can lead to positive safety outcomes and low rates of reoperation.[20]

Reduction quality and implant placement were not consistently reported in the studies reviewed. Achieving excellent reduction, including open reduction if necessary, and using standardized intraoperative imaging to ensure correct implant placement can both lower the need for revision or conversion and lower the incidence of AVN.[42-44] Reduction quality and measures of implant placement should be assessed during treatment and reported in further studies to enable future analyses to accurately compare implants.

Limitations

The primary limitation of our review was the lack of prospective studies on patients treated with FNS, particularly the lack of RCTs. Heterogeneity in study design and patient and procedure characteristics prevented a broader meta-analysis, including studies that did not report use of FNS. This variability is likely due to heterogeneity in trauma patients, as well as differences in study designs. Many data elements were reported inconsistently, especially perioperative and postoperative complications. As mentioned above, methods for measuring blood loss varied widely, introducing heterogeneity into the data and precludes a definitive conclusion. Variations in fracture classification, patient age, follow-up time, mechanism of injury, and data collection methodologies between studies likely contributed to the heterogeneity of the results. Additionally, over half of the included studies had high risk of bias. Lack of comparability between cohorts was a common source of risk of bias, likely due to the heterogenous nature of trauma patient presentation. Finally, all but 1 study[19] in this review did not have long enough follow-up for the outcomes of interest to occur, indicating a need for longer-term studies on FNF treatment with FNS to verify these findings.

Conclusions

FNS can be a safe and effective treatment for FNF, including in older patients, with published incidences of complications similar to comparable treatment options. Further studies are necessary to prospectively compare FNS to other operative treatments.

Appendix

List of Abbreviations

API	Application program interface
AVN	avascular necrosis
CT	computed tomography
DVT	deep vein thrombosis
FNF	femoral neck fracture
FNS	femoral neck system
IQR	interquartile range
MRI	magnetic resonance imagery
PRISMA	Preferred reporting items for systematic reviews and meta-analyses
PROSPERO	International prospective register of systematic reviews
RCT	randomized controlled trial
RoB	risk of bias
SHS	sliding hip screw
SD	standard deviation

Acknowledgements

The authors acknowledge Superior Medical Experts and Nested Knowledge, Inc. for research and editorial assistance. The authors acknowledge Karl Holub, Stephen Mead, Jeffrey Johnson, and Darian Lehmann-Plantenberg for their design, development, and support of the Nested Knowledge meta-analytical software.

Author Contributions

ES contributed to the study design and drafted and revised the manuscript. MK, KH, and RT contributed to the data acquisition. NJH contributed to the study design and the acquisition and analysis of the data. JMP contributed to the study design, data analysis, and drafting and revision of the manuscript. AP and MB contributed to the conception and design of the study and the revision of the manuscript. All authors read and approved the final manuscript.

Declaration of Conflicting Interests

The author(s) declared the following potential conflicts of interest with respect to the research, authorship, and/or publication of this article: ES is employed by and hold equity in Superior Medical Experts. JMP is employed by and hold equity in Superior Medical Experts and Nested Knowledge. MK and RT are employed by Nested Knowledge. KH is employed by Superior Medical Experts and Nested Knowledge. NJH is employed by and holds

equity in Nested Knowledge. AP and MB are employed by Johnson & Johnson (JnJ) and own stock in the company.

Funding

The author(s) disclosed receipt of the following financial support for the research, authorship, and/or publication of this article: This study is sponsored by Johnson & Johnson.

Ethical Statement

Ethical Approval

Institutional Review Board approval and patient consent is not required for this study type.

Informed Consent

Not applicable.

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Supplemental Material

Supplemental material for this article is available online.

References

1. Davidovitch RI, Jordan CJ, Egol KA, Vrahas MS. Challenges in the treatment of femoral neck fractures in the nonelderly adult. *J Trauma*. 2010;68(1):236-242.
2. Lu-Yao GL, Keller RB, Littenberg B, Wennberg JE. Outcomes after displaced fractures of the femoral neck. A meta-analysis of one hundred and six published reports. *J Bone Joint Surg Am*. 1994;76(1):15-25.
3. *Femoral Neck System (FNS)*; 2023; https://www.jnjmedtech.com/en-US/product/femoral-neck-system. (Accessed May 05 2023).
4. Cha Y, Song JU, Yoo JI, et al. Improved control over implant anchorage under the use of the femoral neck system for fixation of femoral neck fractures: a technical note. *BMC Muscoskel Disord*. 2021;22(1):621.
5. *DePuy Synthes Report: Static Cut through Rotation Test in Bone Foam*. DePuy Synthes; 2016:0000165855.
6. *DePuy Synthes Report: Static Cut through Rotation Test in Bone Foam*. DePuy Synthes; 2018:0000277853.
7. Stoffel K, Zderic I, Gras F, et al. Biomechanical evaluation of the femoral neck system in unstable Pauwels III femoral neck fractures: a comparison with the dynamic hip screw and cannulated screws. *J Orthop Trauma*. 2017;31(3):131-137.
8. Moher D, Liberati A, Tetzlaff J, Altman DG, PRISMA Group. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *J Clin Epidemiol*. 2009;62(10):1006-1012.
9. Stang A. Critical evaluation of the Newcastle-Ottawa scale for the assessment of the quality of nonrandomized studies in meta-analyses. *Eur J Epidemiol*. 2010;25(9): 603-605.
10. Sharmin S, Kypri K, Khanam M, Wadolowski M, Bruno R, Mattick RP. Parental supply of alcohol in childhood and risky drinking in adolescence: systematic review and meta-analysis. *Int J Environ Res Publ Health*. 2017;14(3):287.
11. Cintean R, Pankratz C, Hofmann M, Gebhard F, Schütze K. Early results in non-displaced femoral neck fractures using the femoral neck system. *Geriatr Orthop Surg Rehabil*. 2021;12:21514593211050153.
12. Davidson A, Blum S, Harats E, et al. Neck of femur fractures treated with the femoral neck system: outcomes of one hundred and two patients and literature review. *Int Orthop*. 2022;46(9):2105-2115.
13. He C, Lu Y, Wang Q, et al. Comparison of the clinical efficacy of a femoral neck system versus cannulated screws in the treatment of femoral neck fracture in young adults. *BMC Muscoskel Disord*. 2021;22(1):994.
14. Hu H, Cheng J, Feng M, Gao Z, Wu J, Lu S. Clinical outcome of femoral neck system versus cannulated compression screws for fixation of femoral neck fracture in younger patients. *J Orthop Surg Res*. 2021;16(1):370.
15. Nibe Y, Matsumura T, Takahashi T, Kubo T, Matsumoto Y, Takeshita K. A comparison between the femoral neck system and other implants for elderly patients with femoral neck fracture: a preliminary report of a newly developed implant. *J Orthop Sci*. 2021;27(4):876-880. Online ahead of print.
16. Niemann M, Braun KF, Ahmad SS, Stöckle U, Märdian S, Graef F. Comparing perioperative outcome measures of the dynamic hip screw and the femoral neck system. *Medicina (Kaunas)*. 2022;58(3):352.
17. Schuetze K, Burkhardt J, Pankratz C, et al. Is new always better: comparison of the femoral neck system and the dynamic hip screw in the treatment of femoral neck fractures. *Arch Orthop Trauma Surg*. 2023;143(6): 3155-3161.
18. Stassen RC, Jeuken RM, Boonen B, Meesters B, de Loos ER, van Vugt R. First clinical results of 1-year follow-up of the femoral neck system for internal fixation of femoral neck fractures. *Arch Orthop Trauma Surg*. 2022;142(12): 3755-3763.
19. Tang Y, Zhang Z, Wang L, Xiong W, Fang Q, Wang G. Femoral neck system versus inverted cannulated cancellous screw for the treatment of femoral neck fractures in adults: a preliminary comparative study. *J Orthop Surg Res*. 2021; 16(1):504.
20. Vazquez O, Gamulin A, Hannouche D, Belaieff W. Osteosynthesis of non-displaced femoral neck fractures in the elderly population using the femoral neck system (FNS): short-term clinical and radiological outcomes. *J Orthop Surg Res*. 2021;16(1):477.

21. Xu X, Fan J, Zhou F, et al. Comparison of femoral neck system to multiple cancellous screws and dynamic hip screws in the treatment of femoral neck fractures. *Injury.* 2022;2:S28-S35. online ahead of print.
22. Zhang Y-Z, Lin Y, Li C, et al. A comparative analysis of femoral neck system and three cannulated screws fixation in the treatment of femoral neck fractures: a six-month follow-up. *Orthop Surg*. 2022;14(4):686-693.
23. Zhou XQ, Li ZQ, Xu RJ, et al. Comparison of early clinical results for femoral neck system and cannulated screws in the treatment of unstable femoral neck fractures. *Orthop Surg*. 2021;13(6):1802-1809.
24. Xia Y, Zhang W, Zhang Z, Wang J, Yan L. Treatment of femoral neck fractures: sliding hip screw or cannulated screws? A meta-analysis. *J Orthop Surg Res*. 2021;16(1):54.
25. Lim EJ, Shon H-C, Cho J-W, Oh J-K, Kim J, Kim C-H. Dynamic hip screw versus cannulated cancellous screw in Pauwels type II or type III femoral neck fracture: a systematic review and meta-analysis. *J Personalized Med*. 2021;11(10):1017.
26. Stegelmann SD, Butler JT, Mathews DJ, Ostlie HC, Boothby BC, Phillips SA. Survivability of the Femoral Neck System for the treatment of femoral neck fractures in adults. *Eur J Orthop Surg Traumatol*. 2023;33(6):2555-2563.
27. Wang K, Lin D, Chen P, et al. Incidence and factors influencing neck shortening after screw fixation of femoral neck fractures with the femoral neck system. *J Orthop Surg Res*. 2023;18(1):317.
28. Jiang T, Gao H, Xu B, Lv F, Liu T. The comparison of femoral neck system and cancellous screws internal fixation for femoral neck fracture. *Biotechnol Genet Eng Rev*. 2023; 12:1-12.
29. Wang H, Wang B, Zhao C, Song L, Zhu L. Efficacy of femoral neck system fixation vs KHS femoral neck dynamic compression locking plate system in femoral neck fracture. *Alternative Ther Health Med*. 2023;29(5):97-101.
30. Rogers NB, Hartline BE, Achor TS, et al. Improving the diagnosis of ipsilateral femoral neck and shaft fractures: a new imaging protocol. *J Bone Joint Surg Am*. 2020;102(4): 309-314.
31. Sadozai Z, Davies R, Warner J. The sensitivity of ct scans in diagnosing occult femoral neck fractures. *Injury*. 2016; 47(12):2769-2771.
32. Zamora T, Klaber I, Ananias J, et al. The influence of the CT scan in the evaluation and treatment of nondisplaced femoral neck fractures in the elderly. *J Orthop Surg*. 2019;27(2): 2309499019836160.
33. Ly TV, Swiontkowski MF. Management of femoral neck fractures in young adults. *Indian J Orthop*. 2008;42(1):3-12.
34. Stockton DJ, O'Hara LM, O'Hara NN, Lefaivre KA, O'Brien PJ, Slobogean GP. High rate of reoperation and conversion to total hip arthroplasty after internal fixation of young femoral neck fractures: a population-based study of 796 patients. *Acta Orthop*. 2019;90(1):21-25.
35. Wang SH, Yang JJ, Shen HC, Lin LC, Lee MS, Pan RY. Using a modified Pauwels method to predict the outcome of femoral neck fracture in relatively young patients. *Injury*. 2015;46(10):1969-1974.
36. Lin S, Li J, Wang R, et al. The effect of anteromedial support plate with three cannulated screws in the treatment of Pauwels type III femoral neck fracture in young adults. *Eur J Trauma Emerg Surg*. 2022;48(5):4011-4017. Online ahead of print.
37. Ye Y, Chen K, Tian K, Li W, Mauffrey C, Hak DJ. Medial buttress plate augmentation of cannulated screw fixation in vertically unstable femoral neck fractures: surgical technique and preliminary results. *Injury*. 2017;48(10):2189-2193.
38. Kunapuli SC, Schramski MJ, Lee AS, et al. Biomechanical analysis of augmented plate fixation for the treatment of vertical shear femoral neck fractures. *J Orthop Trauma*. 2015;29(3):144-150.
39. Su Z, Liang L, Hao Y. Medial femoral plate with cannulated screw for Pauwels type III femoral neck fracture: a meta-analysis. *J Back Musculoskelet Rehabil*. 2021;34(2):169-177.
40. Fischer H, Maleitzke T, Eder C, Ahmad S, Stöckle U, Braun KF. Management of proximal femur fractures in the elderly: current concepts and treatment options. *Eur J Med Res*. 2021;26(1):86.
41. Upadhyay A, Jain P, Mishra P, Maini L, Gautum VK, Dhaon BK. Delayed internal fixation of fractures of the neck of the femur in young adults. A prospective, randomised study comparing closed and open reduction. *J Bone Joint Surg Br*. 2004;86(7):1035-1040.
42. Wang Y, Ma JX, Yin T, et al. Correlation between reduction quality of femoral neck fracture and femoral head necrosis based on biomechanics. *Orthop Surg*. 2019;11(2): 318-324.
43. Zhu J, Li Y, Zhang Y, Cheng X. Clinical outcome and biomechanical analysis of dynamic hip screw combined with derotation screw in treating displaced femoral neck fractures based on different reduction qualities in young patients (≤65 years of age). *BioMed Res Int*. 2022;2022: 9505667.
44. Nyholm AM, Palm H, Sandholdt H, Troelsen A, Gromov K, Danish Fracture Database Collaborators. Osteosynthesis with parallel implants in the treatment of femoral neck fractures: minimal effect of implant position on risk of reoperation. *J Bone Joint Surg Am*. 2018;100(19): 1682-1690.