Original Article
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Comparative Short-Term Outcomes of Femoral Neck System (FNS) and Cannulated Screw Fixation in Patients with Femoral Neck Fractures: A Multicenter Study

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Background: Femoral neck fractures need to be treated in their early stages with accurate reduction and stable fixation to reduce complications. The authors compared the early radiologic outcomes of femoral neck fractures treated with the recently introduced Femoral Neck System (FNS, Depuy-Synthes) with conventional cannulated screws (CS) in a multicenter design. Furthermore, the factors associated with early failure after FNS were analyzed.

Methods: The FNS group included 40 patients treated between June 2019 and January 2020, and the CS group included 65 patients treated between January 2015 and May 2019. The operation was performed in 3 university hospitals. Patient demographics, fracture classification, postoperative reduction quality, sliding distance of FNS or CS, union and time to union, and complication rates were examined. Logistic regression analysis was performed on candidate factors for early failure of the FNS group.

Results: The FNS group had a 90% union rate and a mean time to union of 4.4 months, while the CS group had similar results with an 83.1% union rate and a mean time to union of 5.1 months. In the subgroup analysis of Pauwels type III fractures, the union rates were 75.0% and 58.8% in the FNS and CS groups, respectively, and the time to union was significantly shorter in the FNS group with 4.8 months compared to 6.8 months in the CS group. Early failure rate within 6 months of FNS fixation was observed to be 10%, which included 3 reduction failures and 1 excessive sliding with a broken implant. Risk factors for early failure after FNS were identified as displaced fractures (Garden classification type III or IV), poor reduction quality, longer tip-apex distance, greater sliding distance, and 1-hole implants, of which sliding distance was the only significant risk factor in multivariate analysis.

Conclusions: In femoral neck fractures, FNS and CS did not show significant differences for short-term radiologic results. FNS resulted in shorter operative time than cannulated screw fixation and favorable outcomes in Pauwels type III femoral neck fractures. The FNS could be considered a reliable and safe alternative to CS when treating femoral neck fractures.

Keywords: *Femoral neck fracture, Internal fixation, Femoral neck system, Cannulated screw*

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Treatment for femoral neck fractures differs depending on the mechanism of injury and age. Femoral neck fractures occurring with low-energy injury in elderly patients are increasing and frequently treated with arthroplasty.[1)] However, in young patients, femoral neck fractures with high-energy injuries need to be fixed, and bony union must be achieved.[2,3)] Femoral neck fractures with high-energy injuries often show displacement with comminution, a larger Pauwels angle, and varus angulation.[4,5] High-energy femoral neck fractures are often accompanied by injuries of the medial femoral circumflex artery and can cause avascular necrosis (AVN; 15%–50%).[6] Fractures with large displacement and a large Pauwels angle have a high risk of nonunion (5%–30%).[7,8] To achieve successful treatment results in femoral neck fractures of young patients, anatomical reduction with firm fixation is essential.[9,10] Various fixation methods are currently available, including multiple cannulated screws (CS) or dynamic hip screws with or without anti-rotation screws.[11,12] Recently, a newly developed implant called the Femoral Neck System (FNS; DePuy-Synthes) was introduced. The FNS combines the minimally invasive advantages of CS with the angle-stable fixation advantages of dynamic hip screws, with bolts and anti-rotation screws inserted proximally into the lateral plate and 1 or 2 locking screws inserted distally to act as a fixed-angle construct.[13] The stability of the FNS construct has been reported in biomechanical experiments.[13,14] Clinical outcomes of FNS have also been reported, but current comparative studies are single-center studies, and multicenter studies are limited.[15] Moreover, risk factors for early failure after FNS have been studied, but need further elucidation.[16] Therefore, the authors of this study sought to compare early radiologic outcomes of femoral neck fractures treated with the recently introduced FNS with conventional CS in a multicenter design. Furthermore, the factors associated with early failure after FNS were analyzed.

METHODS

This study was approved by the Institutional Review Board of Hanyang University Hospital (No. 2020-10-037-001). Informed consent was waived due to the retrospective nature of the study. Three orthopedic surgeons (HJC, YK, and KTH) at three different trauma centers treated femoral neck fractures using FNS from June 2019 to January 2020 and conventional CS fixation methods from January 2015 to May 2019. Patients treated with CS were selected as the control group. Cases of acute traumatic femoral neck fractures in patients ≥ 19 years of age were included in this study. Patients with the following circumstances were excluded from the study: surgery performed more than 48 hours after onset, coexisting infection, other existing fractures, and a follow-up period of less than 6 months. Finally, a total of 40 patients treated with FNS and 65 patients treated with CS fixation were included in this retrospective study.

The surgery was performed under general anesthesia, with the patient positioned on the fracture table and under C-arm guidance. The method of fracture reduction was left to the discretion of each surgeon; however, closed reduction was performed in all cases and no open reduction was performed. Fixation with FNS was performed by placing the guide wire in a center-to-center position on the femoral head after achieving adequate reduction. Bolt was then connected to the lateral plate and inserted towards the femoral head, followed by an anti-rotation screw. The locking screw was then fixed distally. The type of lateral plate (1-hole or 2-hole plate) was left to the surgeon's decision. For fixation with multiple CS, 3 CS were inserted parallel to the femoral head in an inverted triangle shape, with the screw tips placed within 5–10 mm of the subchondral bone.[17] All CS were partially threaded, and the insertion point on the lateral aspect of the femur was positioned superior to the lesser trochanter to prevent stress-rising effects.

Patient demographics including age, sex, follow-up period, bone mineral density, and osteoporosis status were collected through electronic medical record review, as well as operative time. The fracture site (right or left), fracture location (subcapital/transcervical/basicervical), and fracture classification (Garden, Pauwels classification) were investigated on anteroposterior (AP) and lateral plain radiographs, and the presence of comminuted fragments at the fracture site was examined on computed tomography (CT). To assess the reduction status after internal fixation of the fracture, the Garden alignment index, Lowell's criteria, displacement of the femoral neck fracture site, and sliding distance were examined. In the FNS cases, the position of the implant, tip-apex distance (TAD), and the type of lateral plate were further investigated. Garden alignment index was measured on AP and lateral hip plain radiographs. For the AP view, the angle between the femoral shaft medial cortex and the center of the primary compressive trabeculae of the femoral head was measured and defined as good if it was 160°–175° and poor otherwise. In the lateral view, it was defined as good if the angle between the primary compressive trabeculae and the femoral shaft was 170°–190°, and poor otherwise. Lowell's criteria were also evaluated on AP and lateral simple hip radiographs. It was defined as "Intact S" if the cortical bone of the femoral head and neck showed continuity with an S or inverted S-shaped curve in both AP and lateral views, and "Broken S" if the cortical continuity showed to be flat or angled in either AP or lateral views. Fracture site displacement was evaluated by CT performed in the immediate postoperative period, and the reduction quality was considered poor if more than 2 mm of displacement was observed. Sliding distance for CS was defined as the largest value of the distance protruding laterally from the lateral cortex on the follow-up AP radiograph, and for FNS as the difference between the length of the bolt on the immediate postoperative and follow-up AP radiographs.[18,19] For implant position, it was defined as good if the bolt of FNS was within 10 mm of the center on the AP radiograph and located center or within 10 mm anteriorly on the lateral radiograph, and poor otherwise.[20] The TAD was defined as the sum of the distance from the tip of the bolt to the femoral head apex on the AP and lateral plain radiographs.[21]

Active range-of-motion exercises were initiated immediately after surgery. Depending on the patient's condition, partial weight-bearing with crutches or a walker was allowed from toe touch and then gradually increased as pain tolerated. Subsequently, once the patient was deemed capable of full weight-bearing, the walking aid was removed, and independent ambulation was initiated. Patients visited the orthopedic outpatient clinic every month for the first 3 months after the surgery and every 3 months thereafter. Plain radiographs (Hip AP, axial, and both oblique views) were performed at each patient visit. Plain radiographs at 3 months postoperatively were compared with immediate postoperative plain radiographs to measure the sliding distance in the FNS and CS groups, respectively. CT was performed to assess union status if union did not occur within the expected time frame during follow-up. Bone union was defined when the fracture line disappeared, and bridging was observed in at least 3 of the 4 cortices in AP and lateral views (Fig. 1). Nonunion was defined as failure to achieve union more than 6 months after surgery[22] (Fig. 2). The development of biological complications such as AVN and mechanical complications such as screw loosening, cut-out, varus collapse, or implant breakage were investigated. Failure was defined as nonunion or reoperation due to biological or mechanical complications. Three orthopedic surgeons who completed orthopedic trauma fellowship (IK, HJC, and KTH) independently measured the radiologic data. Disagreements were resolved through discussion.

Statistical Analysis

Patients were divided into groups treated with FNS and CS to compare demographic and clinical characteristics. In addition, based on the previous reports that Pauwels classification type III is biomechanically more unstable and exhibits inferior clinical outcomes than type I or II, we performed a subgroup analysis of patients with Pauwels classification type III fractures and compared the demographic and clinical characteristics of the FNS and

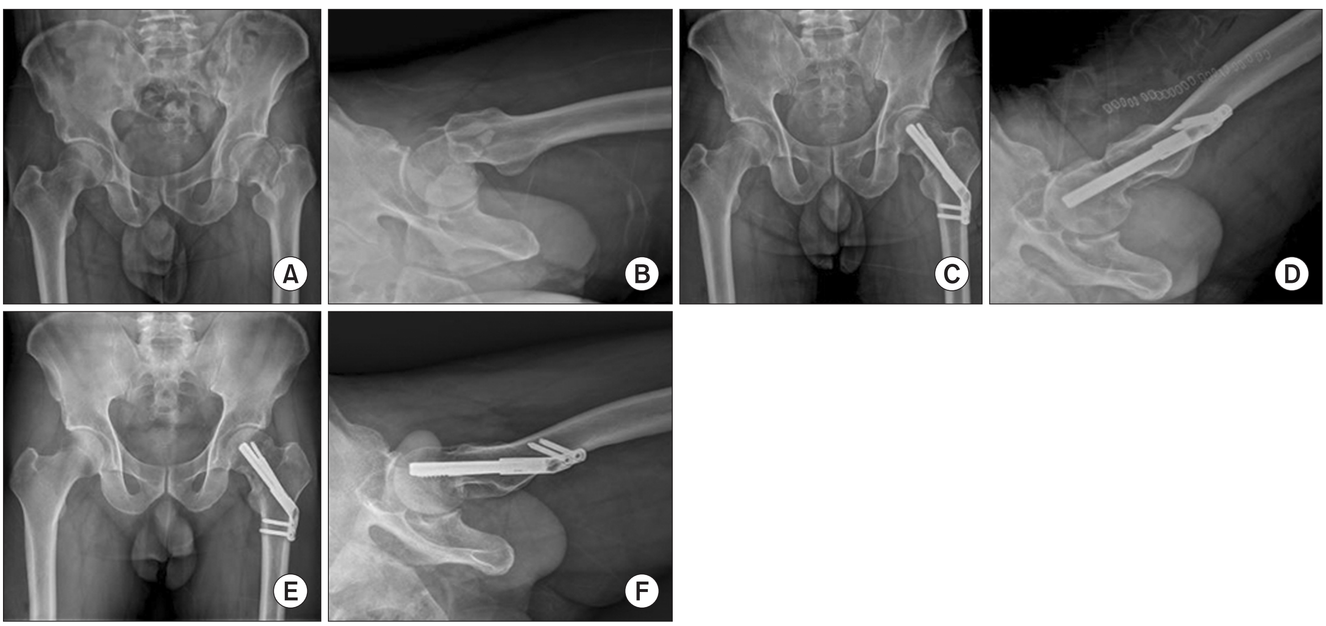

Fig. 1. Anteroposterior (A) and lateral (B) simple radiographs of a left femoral neck fracture following a bicycle accident in a 51-year-old male patient. A displaced fracture corresponding to Garden's classification type IV and a fracture line corresponding to Pauwels classification type III were observed. The patient underwent closed reduction and internal fixation with a Femoral Neck System (FNS) implant. Immediate postoperative anteroposterior (C) and lateral (D) simple radiographs. Note the proper positioning of the FNS implant and good reduction quality. Anteroposterior (E) and lateral (F) simple radiographs at 5 months postoperatively. The patient achieved an uneventful union.

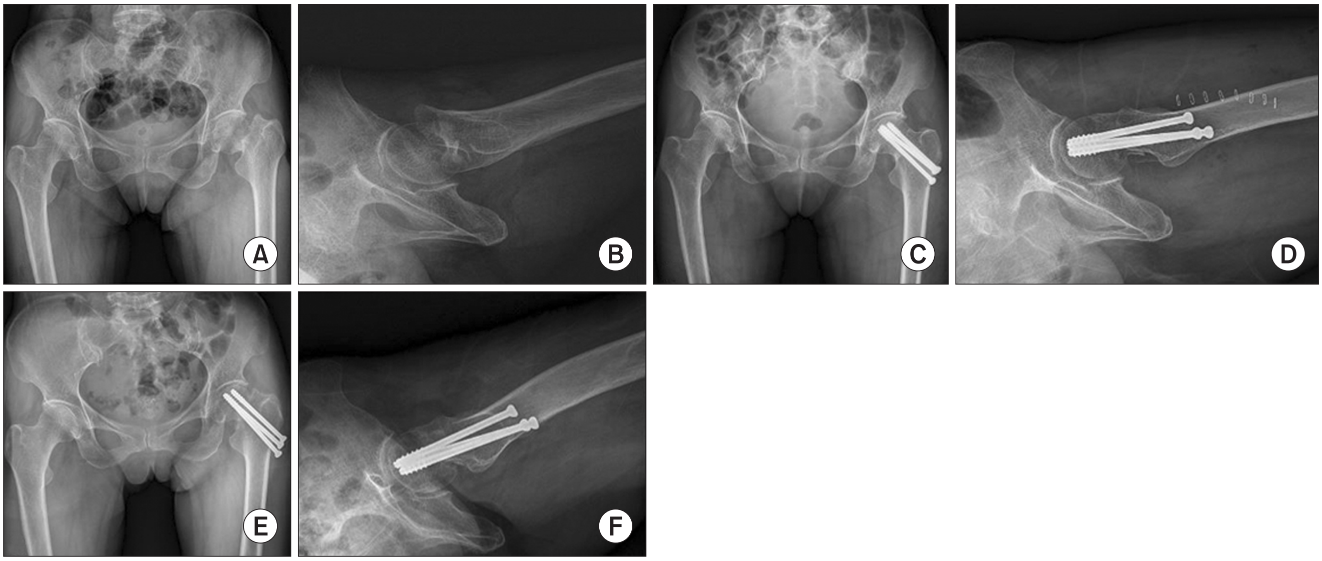

Fig. 2. Anteroposterior (A) and lateral (B) simple radiographs of a left femoral neck fracture following a ground-level fall in a 62-year-old female patient. A fracture corresponding to Garden's classification type IV and Pauwels classification type III was observed. The patient underwent closed reduction and internal fixation with 3 cannulated screws. Immediate postoperative anteroposterior (C) and lateral (D) simple radiographs. Suboptimal reduction quality was noted. Anteroposterior (E) and lateral (F) simple radiographs at 3 months postoperatively. Failure of varus collapse and excessive sliding of the cannulated screws were observed.

CS groups.[13,23] Finally, to identify risk factors for early failure after FNS surgery, univariate and multivariate logistic regression analyses were performed on patients who underwent FNS fixation, divided into a union group and a failure group at 6 months postoperatively. A chi-square test and Fischer's exact test were used to analyze categorical variables. Continuous variables were tested for normality using the Shapiro-Wilk test. Variables that satisfied normality were analyzed with the Student *t*-test, and those that did not were analyzed with the Mann-Whitney *U*-test. Univariate logistic regression analysis was performed on candidate factors to identify risk factors for early failure after FNS. Factors with a p-value < 0.1 were entered into a forward stepwise multiple regression analysis. The logistic regression data were presented as odds ratios (ORs) and 95% confidence intervals (CIs). Fleiss' kappa value was measured to ensure that the radiologic assessments of the 3 orthopedic trauma surgeons were in consensus. IBM SPSS software (version 27.0; IBM Corp.) was used for statistical analysis, and p-values less than 0.05 were considered significant.

RESULTS

The mean age of the overall patient cohort was 57.1 years (range, 30–77 years), with 47 men (44.8%) and 58 women (55.2%). The mean follow-up was 19.9 months (range, 6–57 months). Osteoporosis was diagnosed in 39 patients (37.1%). Fracture location was subcapital in 56 patients (53.3%), transcervical in 46 (43.8%), and basicervical in 3 (2.9%). Garden classification type I was the most common (40 patients, 38.1%), followed by type III (26 patients, 24.8%), type II (24 patients, 22.9%), and type IV (15 patients, 14.3%). In terms of Pauwels classification, type II was most common with 56 patients (53.3%), followed by type III and type I with 29 (27.6%) and 20 (19.1%), respectively. Comminuted fragments were identified in 77 patients (73.3%).

There were no significant differences in demographics or fracture classification between the FNS and CS groups (Table 1). Mean operative time was significantly shorter in the FNS group with 50.0 ± 11.3 minutes compared to 59.1 ± 10.6 minutes in the CS group (p = 0.025) (Table 1). When comparing the radiologic data between the 2 groups, there was no significant difference in the postoperative reduction quality as assessed by the Garden alignment index, Lowell's criteria, and the degree of displacement measured by CT (Table 2). The mean TAD of the FNS group was 8.7 ± 3.0 mm on the AP, 10.4 ± 3.0 mm in the lateral, and a total of 19.2 ± 5.4 mm. The mean sliding distance measured at 3 months postoperatively was 2.7 ± 2.9 mm in the FNS group and 3.4 ± 4.3 mm in the CS group, with no significant difference (p = 0.674) (Table 2). The union rate was 90.0% in the FNS group and 83.1% in the CS group, which

Table 1. Baseline Demographics and Fracture Classification of the Patients

Variable	FNS device (n = 40)	Cannulated screw (n = 65)	*p*-value
Age (yr)	58.7 ± 10.5	55.9 ± 15.0	0.259
Sex			0.658
Male	19 (47.5)	28 (43.1)	
Female	21 (52.5)	37 (56.9)	
Follow-up period (mo)	17.5 ± 10.7	21.3 ± 13.5	0.121
BMD	–1.9 ± 1.2	–1.9 ± 1.4	0.828
Diagnostic category			0.901
Normal	7 (17.5)	14 (21.5)	
Osteopenia	18 (45.0)	27 (41.5)	
Osteoporosis	15 (37.5)	24 (36.9)	
Operative time (min)	50.0 ± 11.3	59.1 ± 10.6	0.025
Site			0.432
Right	19 (47.5)	36 (55.4)	
Left	21 (52.5)	29 (44.6)	
Location			0.168
Subcapital	26 (65.0)	30 (45.2)	
Transcervical	13 (32.5)	33 (50.8)	
Basicervical	1 (2.5)	2 (3.1)	
Garden classification			0.461
Type I	18 (45.0)	22 (33.8)	
Type II	6 (15.0)	18 (27.7)	
Type III	10 (25.0)	16 (24.6)	
Type IV	6 (15.0)	9 (13.8)	
Pauwels classification			0.895
Type I	7 (17.5)	13 (20.0)	
Type II	21 (52.5)	35 (53.8)	
Type III	12 (30.0)	17 (26.2)	
Comminuted fragment			0.762
Present	10 (25.0)	18 (27.7)	
Absent	30 (75.0)	47 (72.3)	

Values are presented as mean ± standard deviation or number (%).
FNS: Femoral Neck System (DePuy Synthes), BMD: bone mineral density.

Table 2. Radiologic Outcome of the Patients

Variable	FNS device (n = 40)	Cannulated screw (n = 65)	*p*-value
Garden alignment index (AP view)			0.788
Good	37 (92.5)	61 (93.8)	
Poor	3 (7.5)	4 (6.2)	
Garden alignment index (lateral view)			1.000
Good	40 (100.0)	64 (98.5)	
Poor	0	1 (1.5)	
Lowell's criteria			0.159
Intact S	19 (47.5)	40 (61.5)	
Broken S	21 (52.5)	25 (38.5)	
CT reduction status			0.751
Displacement ≤ 2 mm	33 (82.5)	52 (80.0)	
Displacement > 2 mm	7 (17.5)	13 (20.0)	
Sliding distance (mm)	2.7 ± 2.9	3.4 ± 4.3	0.674
Outcome			0.399
Union	36 (90.0)	54 (83.1)	
Failure	4 (10.0)	11 (16.9)	
Time to union (mo)	4.4 ± 0.9	5.1 ± 1.6	0.095

Values are presented as number (%) or mean ± standard deviation.
FNS: Femoral Neck System (DePuy Synthes), AP: anteroposterior, CT: computed tomography.

was not significantly different ($p = 0.399$) (Table 2). The 4 failure cases (10.0%) in the FNS group were 3 cases of varus collapse and 1 case of implant breakage. The 11 failure cases (16.9%) in the CS group included 4 nonunion, 2 AVN, and 5 varus collapses. The mean time to union was 4.4 ± 0.9 months in the FNS group and 5.1 ± 1.6 months in the CS group, which tended to be shorter in the FNS group, but this did not reach statistical significance ($p = 0.095$) (Table 2).

A subgroup analysis was performed on Pauwels classification type III fractures. A total of 29 patients were included, 12 in the FNS group and 17 in the CS group. In the subgroup analysis, there were no significant differences in demographics, operative time, and fracture classification between the FNS and CS groups (Table 3). Postoperative reduction quality did not show any difference between the 2 groups (Table 4). The mean sliding distance was 4.4 ± 3.3 mm in the FNS group and 6.0 ± 4.0 mm in the CS group, which was not significantly different between the 2 groups

Table 3. Baseline Demographics and Fracture Classification of the Patients (Pauwels Classification Type III)

Variable	FNS device (n = 12)	Cannulated screw (n = 17)	*p*-value
Age (yr)	57.9 ± 10.0	56.8 ± 13.4	0.453
Sex			0.822
Male	8 (66.7)	12 (70.6)	
Female	4 (33.3)	5 (29.4)	
Follow-up period (mo)	23.0 ± 2.8	25.8 ± 20.7	1.000
BMD	–1.4 ± 1.0	–1.8 ± 1.5	0.481
Diagnostic category			0.700
Normal	4 (33.3)	3 (17.6)	
Osteopenia	6 (50.0)	9 (52.9)	
Osteoporosis	2 (16.7)	5 (29.4)	
Operative time (min)	52.0 ± 7.6	62.5 ± 16.4	0.202
Site			0.428
Right	6 (50.0)	6 (35.3)	
Left	6 (50.0)	11 (64.7)	
Location			0.606
Subcapital	2 (16.7)	1 (5.9)	
Transcervical	9 (75.0)	15 (88.2)	
Basicervical	1 (8.3)	1 (5.9)	
Garden classification			0.174
Type I	0	1 (5.9)	
Type II	0	4 (23.5)	
Type III	8 (66.7)	6 (35.3)	
Type IV	4 (33.3)	6 (35.3)	
Comminuted fragment			0.451
Present	8 (66.7)	8 (47.1)	
Absent	4 (33.3)	9 (52.9)	

Values are presented as mean ± standard deviation or number (%).
FNS: Femoral Neck System (DePuy Synthes), BMD: bone mineral density.

Table 4. Radiologic Outcome of the Patients (Pauwels Classification Type III)

Variable	FNS device (n = 12)	Cannulated screw (n = 17)	*p*-value
Garden alignment index (AP view)			0.246
Good	12 (100.0)	14 (82.4)	
Poor	0	3 (17.6)	
Garden alignment index (lateral view)			1.000
Good	12 (100.0)	16 (94.1)	
Poor	0	1 (5.9)	
Lowell's criteria			0.428
Intact S	6 (50.0)	6 (35.3)	
Broken S	6 (50.0)	11 (64.7)	
CT reduction status			0.703
Displacement ≤ 2 mm	8 (66.7)	9 (52.9)	
Displacement > 2 mm	4 (33.3)	8 (47.1)	
Sliding distance (mm)	4.4 ± 3.3	6.0 ± 4.0	0.368
Outcome			0.449
Union	9 (75.0)	10 (58.8)	
Failure	3 (25.0)	7 (41.2)	
Time to union (mo)	4.8 ± 0.8	6.8 ± 1.5	0.042

Values are presented as number (%) or mean ± standard deviation.
FNS: Femoral Neck System (DePuy Synthes), AP: anteroposterior, CT: computed tomography.

($p = 0.368$) (Table 4). The mean sliding distance increased by 1.7 mm and 2.6 mm in the FNS and CS groups, respectively, compared to the distance measured in the overall cohort. Nine patients (75.0%) in the FNS group achieved union and 10 patients (58.8%) in the CS group achieved union, with no statistical difference in union rates ($p = 0.449$) (Table 4). The mean time to union, however, was significantly shorter in the FNS group at 4.8 ± 0.8 months compared to 6.8 ± 1.5 months in the CS group ($p = 0.042$) (Table 4).

Logistic regression analysis was performed to identify risk factors for early failure in the FNS group. Univariate analysis showed that Garden classification displaced type (Type III and IV, $p = 0.032$), poor Garden lateral alignment index ($p < 0.001$), broken Lowell's criteria ($p = 0.004$), total TAD (mm, $p = 0.004$), sliding distance ($p = 0.008$), and 1-hole FNS implant ($p = 0.033$) were significantly associated with early failure among the candidate factors (Table 5). Multivariate analysis was performed on factors with a *p*-value less than 0.1, and only sliding distance (OR, 1.79; 95% CI, 1.10–2.90; $p = 0.019$) was identified as a significant risk factor (Table 5).

The Fleiss' kappa values of the radiologic variables in the FNS group were 0.711 for Garden classification, 0.727 for Pauwels classification, 0.957 for the presence of

Table 5. Univariate and Multivariate Analysis of Variables Associated with Early Failure after FNS Fixation for Femoral Neck Fractures (n = 40)

Variable	Univariate analysis		Multivariate analysis	
	Odds ratio (95% CI)	*p*-value	Odds ratio (95% CI)	*p*-value
Age (yr)	1.04 (0.95–1.14)	0.418		
Female sex	0.90 (0.11–7.06)	0.916		
Osteoporosis	1.91 (0.18–20.23)	0.591		
Location				
Subcapital	Reference	-	-	NS
Transcervical	7.50 (0.70–80.96)	0.097	-	NS
Basicervical	-	NS	-	NS
Garden classification				
Non-displaced (type I, II)	Reference	-	-	NS
Displaced (type III, IV)	4.00 (1.13–14.18)	0.032	-	NS
Pauwels classification				
Type I & II	Reference	-		
Type III	2.25 (0.69–7.30)	0.177		
Comminuted fragment				
Present	3.33 (0.92–12.11)	0.067	-	NS
Garden alignment (AP)				
Poor	-	NS		
Garden alignment (lateral)				
Poor	9.00 (3.20–25.29)	< 0.001	-	NS
Lowell's criteria				
Broken S	6.00 (1.77–20.37)	0.004	-	NS
Poor implant position	3.67 (0.29–47.11)	0.319		
CT reduction status				
Displacement > 2 mm	1.33 (0.30–5.96)	0.706		
TAD (mm)	1.13 (1.06–1.20)	< 0.001	-	NS
Sliding distance (mm)	1.91 (1.19–3.07)	0.008	1.79 (1.10–2.90)	0.019
FNS implant				
1-Hole	2.57 (1.70–3.87)	0.033	-	NS

FNS: Femoral Neck System (DePuy Synthes), CI: confidence interval, NS: not significant, AP: anteroposterior, CT: computed tomography, TAD: tip-apex distance.

comminuted fragment, 0.649 for AP Garden index, 0.983 for Lateral Garden index, 0.700 for Lowell's criteria, 0.639 for CT reduction status, and 0.744 for Implant position, all of which showed good agreement above 0.6. The Fleiss kappa values for the CS group showed similarly high agreement with Garden classification of 0.718, Pauwels classification of 0.657, comminuted fragment of 0.926, AP Garden index of 0.639, Lateral Garden index of 0.745, Lowell's criteria of 0.830, and CT reduction status of 0.664.

DISCUSSION

This study is the first multicenter study to compare outcomes between FNS and CS. In our study comparing the radiologic outcomes of FNS and CS fixation of femoral neck fractures, the FNS group had a 90% union rate and a mean time to union of 4.4 months, while the CS group had similar results with an 83.1% union rate and a mean time to union of 5.1 months. In the comparison of biomechanically unstable Pauwels type III fractures, the union rates were 75.0% and 58.8% in the FNS and CS groups, respectively, which were lower than the overall cohort. The union time of Pauwels type III fractures was significantly shorter in the FNS group with 4.8 months compared to 6.8 months in the CS group, and both groups showed a longer time to union than the overall cohort. The early failure rate within 6 months of FNS fixation was observed to be 10%. Risk factors for early failure after FNS included displaced fractures such as Garden classification type III or IV, poor reduction quality, longer TAD, greater sliding distance, and 1-hole implant, of which sliding distance was the only significant factor associated with failure in the multivariate analysis.

A recent study comparing FNS and CS fixation in femoral neck fractures reported no significant difference in union rates and complication rates between the 2 procedures.[24)] Our results also showed no difference in failure rates between the FNS and CS groups. Another study reported a shorter operative time with FNS compared to CS, and we also found that FNS had a significantly shorter operative time than CS.[25)] These results suggest that FNS can be effectively and safely performed as an alternative to CS fixation in femoral neck fractures.

Pauwels III femoral neck fractures have a vertically oriented fracture line, which causes high shear forces, and are known to be difficult to reduce and have a high failure rate.[8,26)] In our study, the reduction quality of Pauwels type III fractures was also poor, with 17 patients (58.6%) having a displacement of > 2 mm, which was 3 times the rate of 20 patients (19.0%) in the overall cohort. In addition, Pauwels type III fractures had a lower union rate and a longer union period than the overall cohort. This indicates that treating Pauwels type III fractures with internal fixation is challenging. In Pauwels type III fractures, FNS was associated with a significantly shorter time to union than CS. It has been reported that CS is biomechanically inferior in Pauwels type III fractures compared to FNS.[13)] Although there was no statistical difference in union time in the overall cohort, the significant difference observed between the 2 methods in Pauwels type III fractures suggests that the higher biomechanical stability of the FNS may have influenced union time by better withstanding vertical shear forces in this unstable fracture type. Based on our findings, the improved stability of the FNS construct observed in biomechanical experiments may have translated into clinical outcomes.

Previous research on risk factors for failure after FNS fixation has reported that displaced fracture type and reduction quality are associated with failure.[16)] In our study, we also found that a displaced fracture and poor reduction quality were risk factors for early failure. Displaced fractures are more difficult to reduce and are more likely to result in poor quality of reduction. It has been reported that reduction quality has a significant impact on failure in internal fixation of femoral neck fractures.[27)] Reduction quality is one of the factors that can be controlled by the surgeon, and our study and previous studies suggest that it is important to achieve anatomical reduction in the treatment of femoral neck fractures, and surgeons should attempt to achieve good reduction quality by using various reduction techniques. TAD was also identified as a risk factor for failure in our study. A higher risk of failure with a longer TAD has been identified in studies using dynamic hip screws in pertrochanteric factures.[21)] This suggests that it is important to keep the TAD short even when using FNS in femoral neck fractures. The risk of failure was higher for 1-hole implants compared to 2-hole implants. A recent finite element analysis study of Pauwels classification angles of 50°, 60°, and 70° found that the biomechanical stability of 1- and 2-hole FNS implants was similar up to 60°, but at fractures of 70°, the 2-hole was more stable than the 1-hole implant.[28)] The results of our study suggest that the findings of this biomechanical study may translate into clinical differences. On the other hand, another finite element analysis study reported that the trajectory of the FNS bolt is more important for biomechanical stability than the type of lateral plate.[19)] Therefore, differences in clinical outcomes based on the type of lateral plate may warrant further study.

Sliding distance was the only significant factor associated with early failure in the multivariate analysis. The sliding of the FNS bolt occurs through weight-bearing, which results in compression of the fracture site. Greater sliding distance causes more neck shortening, and excessive neck shortening is associated with leg length discrepancy and poor clinical outcomes.[29)] Some studies have reported early full weight-bearing after FNS fixation, while others have reported that early ambulation before 6 weeks postoperatively is a risk factor for failure after FNS.[16,30] Our study used a sequential protocol from standing to toe-touch ambulation, gradually increasing partial weight-bearing, followed by full weight-bearing, rather than mandating full weight-bearing at a specific postoperative time point as in other studies, which may have reduced the risk of early failure of the FNS.

There are a couple of limitations in this study, such as its small sample size. This limitation made it difficult to perform an extensive statistical analysis. Furthermore, although the effectiveness of the treatment was evaluated by CT and plain radiography, the patient's subjective evaluation or satisfaction with the treatment was not included in the study. Finally, the follow-up of the FNS group was rather short for analyzing other possible complications that could arise. Nevertheless, the study is of value in that it provides early clinical results in patients treated with an FNS device and analyzes factors associated with early failure of FNS. Future studies with a larger number of patients and longer follow-up periods are needed to further investigate the effectiveness of FNS in femoral neck fractures.

In conclusion, FNS and CS fixation showed comparable short-term radiologic outcomes. FNS resulted in shorter operative time than CS fixation and favorable outcomes in Pauwels type III femur neck fractures. The FNS could be considered as a reliable and safe alternative to CS fixation when treating femoral neck fractures.

CONFLICT OF INTEREST

No potential conflict of interest relevant to this article was reported.

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REFERENCES

1. Ossendorf C, Scheyerer MJ, Wanner GA, Simmen HP, Werner CM. Treatment of femoral neck fractures in elderly patients over 60 years of age: which is the ideal modality of primary joint replacement? Patient Saf Surg. 2010;4(1):16.
2. Collinge CA, Mir H, Reddix R. Fracture morphology of high shear angle "vertical" femoral neck fractures in young adult patients. J Orthop Trauma. 2014;28(5):270-5.
3. Slobogean GP, Sprague SA, Scott T, Bhandari M. Complications following young femoral neck fractures. Injury. 2015; 46(3):484-91.
4. Robinson CM, Court-Brown CM, McQueen MM, Christie J. Hip fractures in adults younger than 50 years of age: epidemiology and results. Clin Orthop Relat Res. 1995;(312):238-46.
5. Marsh JL, Slongo TF, Agel J, et al. Fracture and dislocation classification compendium - 2007: Orthopaedic Trauma Association classification, database and outcomes committee. J Orthop Trauma. 2007;21(10 Suppl):S1-133.
6. Baig SA, Baig MN. Osteonecrosis of the femoral head: etiology, investigations, and management. Cureus. 2018;10(8): e3171.
7. Jo S, Lee SH, Lee HJ. The correlation between the fracture types and the complications after internal fixation of the femoral neck fractures. Hip Pelvis. 2016;28(1):35-42.
8. 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):1969-74.
9. Chan DS. Femoral neck fractures in young patients: state of the art. J Orthop Trauma. 2019;33 Suppl 1:S7-11.
10. Pauyo T, Drager J, Albers A, Harvey EJ. Management of femoral neck fractures in the young patient: a critical analysis review. World J Orthop. 2014;5(3):204-17.
11. Panteli M, Rodham P, Giannoudis PV. Biomechanical rationale for implant choices in femoral neck fracture fixation in the non-elderly. Injury. 2015;46(3):445-52.
12. Lowe JA, Crist BD, Bhandari M, Ferguson TA. Optimal treatment of femoral neck fractures according to patient's physiologic age: an evidence-based review. Orthop Clin North Am. 2010;41(2):157-66.
13. 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):131-7.

14. Moon JK, Lee JI, Hwang KT, Yang JH, Park YS, Park KC. Biomechanical comparison of the femoral neck system and the dynamic hip screw in basicervical femoral neck fractures. Sci Rep. 2022;12(1):7915.

15. Jiang J, Chen J, Xing F, Liu H, Xiang Z. Comparison of femoral neck system versus cannulated screws for treatment of femoral neck fractures: a systematic review and meta-analysis. BMC Musculoskelet Disord. 2023;24(1):285.

16. Zhang Y, Zhang X, Li C, et al. Prediction of hip joint function and analysis of risk factors for internal fixation failure after Femoral Neck System (FNS). BMC Musculoskelet Disord. 2023;24(1):674.

17. Paziuk T, Chang G, Krieg J. Cannulated screw fixation of femoral neck fractures: an intraoperative pearl to avoid a common mistake. Tech Orthop. 2021;36(4):409-11.

18. Stockton DJ, Lefaivre KA, Deakin DE, et al. Incidence, magnitude, and predictors of shortening in young femoral neck fractures. J Orthop Trauma. 2015;29(9):e293-8.

19. Jung CH, Cha Y, Chung JY, et al. Trajectory of bolt and length of plate in femoral neck system determine the stability of femur neck fracture and risk of subsequent subtrochanteric fracture: a finite element analysis. BMC Musculoskelet Disord. 2023;24(1):465.

20. Parker MJ. Cutting-out of the dynamic hip screw related to its position. J Bone Joint Surg Br. 1992;74(4):625.

21. Baumgaertner MR, Curtin SL, Lindskog DM, Keggi JM. The value of the tip-apex distance in predicting failure of fixation of peritrochanteric fractures of the hip. J Bone Joint Surg Am. 1995;77(7):1058-64.

22. Dhar SA, Gani NU, Butt MF, Farooq M, Mir MR. Delayed union of an operated fracture of the femoral neck. J Orthop Traumatol. 2008;9(2):97-9.

23. Shen M, Wang C, Chen H, Rui YF, Zhao S. An update on the Pauwels classification. J Orthop Surg Res. 2016;11(1):161.

24. 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.

25. 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.

26. Cha YH, Yoo JI, Hwang SY, et al. Biomechanical evaluation of internal fixation of Pauwels type III femoral neck fractures: a systematic review of various fixation methods. Clin Orthop Surg. 2019;11(1):1-14.

27. Qiu L, Huang Y, Li G, Wu H, Zhang Y, Zhang Z. Essential role of reliable reduction quality in internal fixation of femoral neck fractures in the non-elderly patients-a propensity score matching analysis. BMC Musculoskelet Disord. 2022;23(1):346.

28. Fan Z, Huang Y, Su H, Jiang T. How to choose the suitable FNS specification in young patients with femoral neck fracture: a finite element analysis. Injury. 2021;52(8):2116-25.

29. Zielinski SM, Keijsers NL, Praet SF, et al. Femoral neck shortening after internal fixation of a femoral neck fracture. Orthopedics. 2013;36(7):e849-58.

30. 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):3155-61.