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Research article

Pre-sliding of the femoral neck system to prevent postoperative shortening of femoral neck fractures

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ABSTRACT

Objective: The purpose of this study is to evaluate the effect of pre-sliding of the femoral neck system (FNS) in the prevention of postoperative femoral neck shortening in femoral neck fractures.

Method: This study was designed to retrospectively analyze data from 109 patients with femoral neck fractures who were admitted to a Level I trauma center between April 2020 and June 2022. Of these patients, 90 were followed up for more than 12 months. The study included 52 males and 38 females, with 35 cases of Garden I and II fractures and 55 cases of Garden III and IV fractures. The Harris Hip Score at 12 months postoperatively were recorded. The patients were divided into two groups based on their surgical records and postoperative radiography: the Pre-sliding group and the No-pre-sliding group. The purpose of this study is to analyze the role of pre-sliding in preventing femoral neck shortening, fracture healing time, degree of postoperative shortening, complications, and Harris Hip Score, and to make a comparison between the two groups.

Results: All 90 patients were followed up for over one year after surgery. A statistically significant difference was observed in the preoperative Garden classification ($P < 0.05$). At 1 year after the operation, the shortening distance was 6.5 ± 6.4 mm in the No-pre-sliding group and 3.9 ± 3.4 mm in the Pre-sliding group. The Harris Hip Score were 88.7 (79.8, 93.5) in the No-pre-sliding group and 94.8 (87.7, 96.9) in the Pre-sliding group, with a statistically significant difference between the two groups ($P < 0.05$). Shortening was concentrated at 3 months postoperatively and reached a stable state within 6 months, with less persistent shortening occurring after 6 months. There was no statistically significant difference in the preoperative baseline data.

Conclusion: Pre-sliding of the FNS prevents postoperative shortening of the femoral neck and improves hip function as measured by the Harris Hip Score.

1. Introduction

Femoral neck fractures (FNF) are the most frequent type of hip fracture, representing over 50% of all hip fractures [1]. It is

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predicted that more than 6 million people worldwide will suffer FNF by 2050 [2]. For young and middle-aged patients with FNF, reduction and fixation are the preferred surgical options [3]. The conventional method for fixation involves the use of multiple cannulated screws and dynamic hip screws [4]. However, the rate of complications following internal fixation of FNF remains high, ranging from 20% to 30% [5,6]. In 2018, the femoral neck system (FNS; DePuy-Synthes, Switzerland) was introduced to fix FNF. Biomechanical tests have shown that FNS provides better prevention of medial collapse and resistance to rotation than conventional methods [7]. At the same time, it can be implanted with a small incision of approximately 4 cm. This technique is favored by trauma and orthopedic surgeonsand has been widely used in China.

The FNS consists of (1) a plate with threaded holes and a barrel, (2) a bolt to support the proximal fragment, (3) an anti-rotation screw and a locking screw (Fig. 1 A). The bolt and anti-rotation screw lock together to secure the proximal fragment, and sliding through the barrel allows dynamic compression of the fracture with a 20 mm sliding space (Fig. 1B and C). The sliding mechanism allows for the application of axial loads that promote fracture healing by compressing the fracture site. However, there may be insufficient contact area between the fracture site to develop an effective anti-shortening mechanism in unstable fractures with suboptimal reduction position or cortical comminution. Evidence from a recent clinical study suggests a 39.1% incidence of femoral neck shortening and a 17.2% incidence of severe shortening (shortening of more than 10 mm) in 87 patients fixed with FNS. Although femoral neck shortening affects postoperative hip function, it does not affect fracture healing rate [8]. Appropriate precautions must be taken to minimize shortening. Adequate compression of the fracture end can prevent moderate or severe shortening, restore the anatomical relationship of the hip, and improve the patient's hip function.

In 2021, Cha et al. reported the use of the pre-sliding technique to adjust the depth of the FNS bolts and improve the value of the tip-apex distance (TAD) [9]. The finite element analysis demonstrated that the use of the pre-sliding technique provided greater stability than the standard fixation technique for Pauwels type III FNF fixed with FNS [10]. To our current knowledge, the pre-sliding technique improves stability but has not been reported to prevent femoral neck shortening.

Since April 2020, we have applied the pre-sliding technique to the FNS treatment of various types of femoral neck fractures. Here, we conducted a retrospective case-control study to analyze the clinical efficacy of the pre-sliding technique and the characteristics of femoral neck shortening after FNS fixation.

2. Materials and methods

2.1. Inclusion and exclusion criteria

This study retrospectively collected cases of unilateral FNF fixed with FNS in the age group of 18–65 years with a fracture-to-surgery time of less than 2 weeks. Exclusion criteria for this study included pathologic fracture, multiple fractures, fracture time longer than 2 weeks, pre-injury combined osteoarthritis or dysplasia of the injured hip joint, combination of other diseases that affect

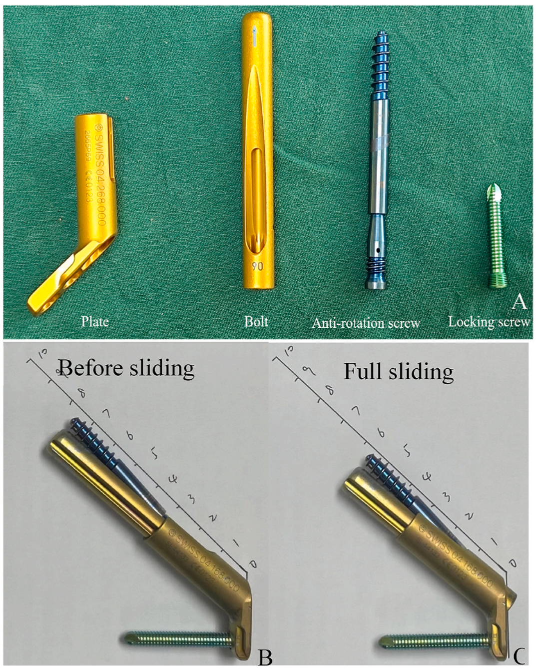

Fig. 1. A The FNS consists of (1) a threaded plate and shaft, (2) a bolt to support the proximal fragment, and (3) an anti-rotation screw. The bolt and anti-rotation screw interlock to secure the proximal fragment, and sliding through the barrel allows dynamic compression of the fracture with 20 mm of sliding space; B Before sliding, with 20 mm of sliding space; C After full sliding, shortened by 20 mm.

self-care, incomplete follow-up data, or follow-up time less than 12 months.

3. General information

This study included 101 patients with FNF who underwent surgery within 2 weeks of injury and met the inclusion criteria. Of these, 11 patients did not complete follow-up, leaving a total of 90 patients who completed more than 12 months of follow-up. Among the patients, there were 52 males and 38 females, with 47 left-sided and 43 right-sided cases. Fractures were classified according to the Garden system: 27 cases were classified as Garden I, 8 as Garden II, 12 as Garden III, and 43 as Garden IV.

Two orthopedic trauma surgeons with specialized training independently measured the imaging data for fracture classification (Garden classification) using anteroposterior hip radiographs. Inconsistencies in results were resolved through discussion and negotiation.

The study followed the guidelines of the Declaration of Helsinki (2013 revision) and received approval from the Medical Ethics Committee office of Fuzhou Second Hospital. Informed consent was obtained from all patients, who signed an informed consent form.

4. Surgery method

After administering general anesthesia, the patient is positioned supine with the healthy side in the lithotomy position. The *C*-arm X-ray fluoroscopy is then used to locate and mark the needle entry point. It is important to maintain sterile conditions throughout the procedure. The neck of the femur is approached from the lateral side, and two K-wires are inserted without exceeding the fracture line. Perform closed reduction and observe the anterior-posterior and lateral X-ray of the hip joint under *C*-arm fluoroscopy to determine the quality of the reduction. After satisfactory reduction, insert the two pre-set K-wires into the femoral head for temporary fixation. A 4 cm longitudinal skin incision was made down the lateral greater tuberosity of the affected thigh, revealing the lateral aspect of the upper end of the femoral shaft. The skin, broad fascia, muscularis propria, and periosteum were incised longitudinally. Using *C*-arm fluoroscopy, the guide pin was drilled through the 130° guide to a depth of approximately 5 mm in the femoral subchondral bone. The Pre-sliding group used a structure that was two sizes larger than recommended by the manufacturer's guideline (10 mm larger than recommended), based on the measured depth of the guide pin embedded in the femoral head. In contrast, the No-pre-sliding group chose the structure recommended by the manufacturer's guideline, based on the measurements. For instance, if the guide pin depth measures 95 mm, 105 mm and 95 mm bolts are used for Pre-sliding group and No-pre-sliding group, respectively. The holes are reamed along the guide pin using a depth-limiting drill, the bolt and plate are assembled, and driven along the guide pin to the appropriate depth, which is 5 mm from the subchondral bone. After confirming the satisfactory position of the bolt and plate on the *C*-arm fluoroscopy, proceed to drill, insert the locking screw in the distal locking hole and place the anti-rotation screw along the guide device. Finally, radiography was used to confirm satisfactory screw position and fracture reduction.

4.1. Postoperative treatment and observation index

To prevent infection, cefazolin sodium was administered. Low molecular weight heparin calcium was injected subcutaneously to prevent deep vein thrombosis. Patients were instructed to maintain a non-weight-bearing status after surgery and gradually transition to partial weight-bearing with crutches (approximately 30 kg) based on the fracture healing status. The speed of weight-bearing increase was determined by two trauma and orthopedic surgeons. Outpatient follow-up was conducted at 1, 2, 3, 6, and 12 months post-surgery. At the 12-month follow-up, hip function was evaluated using the Harris Hip Score, which included four components: pain, functional status, deformity, and range of motion.

4.2. Main indicators and methods for observation measurement

The baseline data included gender, age, BMI, mechanism of injury, side of injury, Garden classification, Pauwels classification, cortical comminution, and whether the pre-sliding technique was used.

Primary outcomes included fracture reduction quality (Garden's alignment index), fracture healing time, degree of femoral neck shortening, Harris hip score, and hip motion.

Assessment of fracture reduction quality: According to Garden's alignment index [11], the quality of the fracture reduction can be classified into four grades. Grade I is achieved when the angle is 160° on anteroposterior radiographs and 180° on lateral radiographs. Grade II is achieved when the angle is between 155° and 160° on anteroposterior radiographs and 180° on lateral radiographs. Grade III is achieved when the angle is between 150° and 155° on anteroposterior radiographs or greater than 180° on lateral radiographs. Grade IV is achieved when the angle is $< 150°$ on anteroposterior radiographs, $>180°$ on lateral radiographs. Diagnostic criteria for fracture healing [12]: The criteria for fracture healing include the absence of percussion pain in the hip joint and lower limbs of the affected side, as well as the presence of continuous bone trabeculae passing through the original fracture site, which is confirmed by X-ray or CT scans. Additionally, the degree of femoral neck shortening should be evaluated. The measurement method reported by Zlowodzki et al. [13] was used to measure the distance of shortening of the femoral head horizontally as the X-axis and vertically as the Y-axis in the orthopantomogram of both hips, mirroring the healthy side to the affected side. The distance of shortening of the femoral neck axis upward was calculated as $Z = Y\sin(\theta) + X\cos(\theta)$ (where θ is the angle between the Y-axis and the axial direction of the femoral neck. Based on the magnitude of Z, the degree of shortening of femoral necks was categorized into mild shortening (0–5 mm), moderate shortening (>5, ≤ 10 mm), and severe shortening (>10 mm). The Harris Hip Score [14] assesses joint mobility, function, pain, and deformity, and ranges from 0 to 100 points. Scores of 90–100 points are considered excellent, 80–89 points are good, 70–79 points are acceptable, and scores of 70 points or less are poor. Higher scores indicate better hip function.

The study evaluated the incidence of postoperative complications [15], as assessed by two attending physicians. These complications included deep incision infection, implant cut-out (implant passing through the femoral head into the joint), implant loosening (displacement of the bone relative to the implant without femoral head cut-out), implant failure (breakage/bending), delay union and non-union, femoral head collapse, and complications leading to arthroplasty.

4.3. Statistical analysis

Statistical analysis was performed using SPSS software (IBM, version 26). The Shapiro-Wilk test was used to determine normal distribution for the measurement data. BMI and shortening distance were found to conform to normal distribution and expressed as mean ± sd. A two independent samples *t*-test was used to compare the two groups. The age, weight-bearing duration, time for fracture healing, and Harris Hip Score did not follow a normal distribution, which was expressed as Median (Q1, Q3). To compare the two groups of patients, the Mann-Whitney *U* test was used. Count data were compared using the $\chi 2$ test. A p-value of less than 0.05 was considered statistically significant. Graphs were created using Prism 9 software.

5. Results

5.1. Baseline information

There were a total of 90 patients, with 42 in the Pre-sliding group and 48 in the No-pre-sliding group. There were no statistically significant differences in the preoperative baseline data between the two groups of patients **(**Table 1**),** including gender, age, BMI, mechanism of injury, side of injury, Pauwels classification, cortical comminution, quality of fracture reduction (Garden's alignment index), and weight-bearing time ($P > 0.05$). However, there was a statistically significant difference in preoperative fracture Garden classification between the two groups of patients ($P < 0.05$).

5.2. Fracture healing time, shortening classification, and hip function

A total of 90 patients with FNF fixed with FNS. The fracture healed in 8.0 (6.0, 10.0) weeks in the No-pre-sliding group and in 6.0 (6.0, 10.0) weeks in the Pre-sliding group. There was no statistically significant difference between the two groups ($Z = -0.941$, $P = 0.347$). After one year from the procedure, the No-pre-sliding group had 27 cases of no shortening and mild shortening (≤5 mm), 7 cases of moderate shortening (>5, ≤10 mm), and 14 cases of severe shortening (>10 mm). The Pre-sliding group had 35 cases of no shortening and mild shortening (≤5 mm), 2 cases of moderate shortening (>5, ≤10 mm), and 3 cases of severe shortening (>10 mm). There was a statistically significant difference between the two groups ($\chi 2 = 8.606$, $P = 0.014$). There were no cases of moderate or severe shortening (shortening >5 mm) in no-displaced femoral neck fractures. However, the incidence of moderate and severe shortening in displaced FNF was 29.2% (7/24) and 58.3% (14/24), respectively. At 1 year postoperatively, the shortening distance was 6.5 ± 6.4 mm in the No-pre-sliding group and 3.9 ± 3.4 mm in the Pre-sliding group, with a statistically significant difference between

Table 1
Comparison of baseline information between Pre-sliding group and No-pre-sliding group.

Group		No-pre-sliding (n = 48)	Pre-sliding (n = 42)	Z/X^2 value	*P* value
Grader	Men(n)	30	22	0.940	0.332
	Women(n)	18	20		
Age (years) M(Q1,Q3)	M (Q1 , Q3)	55.5 (45.0,59.0)	52.5 (39.0,59.0)	−1.158	0.247
BMI (kg/m^2)	M (Q1 , Q3)	23.4 ± 2.2	23.1 ± 2.6	0.716	0.476
Mechanism of injury	Low-energy (n)	14	10	0.392	0.566
	High-energy (n)	34	32		
Side of injury	Left(n)	22	25	1.683	0.195
	Right(n)	26	17		
Garden fracture classifcation	No-displaced (Garden I and II)(n)	24	11	5.343	0.021
	Displaced (Garden III and IV)(n)	24	31		
Pauwels classifcation	Pauwels I(n)	21	10	3.954	0.138
	Pauwels II(n)	14	17		
	Pauwels III(n)	13	15		
Cortical crushing	No(n)	27	17	2.230	0.135
	Yes(n)	21	25		
Garden's alignment index	Acceptable (I and II) (n)	38	32	0.115	0.735
	Unacceptable (III and IV) (n)	10	10		
Weight-bearing time (weeks) M(Q1,Q3)	M (Q1 , Q3)	4.5 (3.0,6.0)	5.0 (4.0,6.0)	−1.137	0.256

the two groups ($t = 2.501$, $p = 0.015$). At 1 year after the operation, the Harris Hip Scores were 88.7 (79.8, 93.5) in the No-pre-sliding group and 94.8 (87.7, 96.9) in the Pre-sliding group. There was a statistically significant difference between the two groups ($Z = -3.099$, $p = 0.002$) (Table 2).

According to whether the fracture was displaced or not, it was categorized into no-displaced fracture (Garden I,II) and displaced fracture (Garden III,IV), of which 35 cases of no-displaced fracture and 55 cases of displaced fracture. There were 24 cases of no shortening and mild shortening (≤5 mm), 0 cases of moderate shortening (>5, ≤10 mm), and 0 cases of severe shortening (>10 mm) in no-displaced fractures using the No-pre-sliding technique, and 11 cases of no shortening and mild shortening (≤5 mm), 0 cases of moderate shortening (>5, ≤10 mm), and 0 cases of severe shortening (>10 mm) in the pre-sliding group. There was no statistical difference between the two groups ($p = 1$). There were 3 cases of no and mild shortening (≤5 mm), 7 cases of moderate shortening (>5, ≤10 mm), and 14 cases of severe shortening (>10 mm) in displaced fractures using the No-pre-sliding technique, 24 cases of no and mild shortening (≤5 mm), 4 cases of moderate shortening (>5, ≤10 mm), and 3 cases of severe shortening (>10 mm). There was a statistical difference between the two groups ($\chi 2 = 23.763$, $P < 0.001$) (Table 3).

5.3. Treatment-related complications

None of the 90 cases had deep incision infection, implant breakage/bending and non-union. Cut-out 2 cases, 2.2% (2/90, 95% CI: 0–5.3), No-pre-sliding group 1 (2.1%) case, Pre-sliding group 1 (2.4%) case. Implant loosening 4 cases, 4.4% (4/90, 95% CI: 0.1–8.8), No-pre-sliding group 1 (2.1%) cases, Pre-sliding group 3 (7.1%) cases. Delayed-union 5 cases, 5.6% (5/90, 95% CI: 0.7–10.4), No-pre-sliding group 3 (6.3%) cases, Pre-sliding group 2 (4.8%) cases. Femoral head collapse 6 cases, 6.7% (6/90, 95% CI: 1.4–11.9), No-pre-sliding group 4 (8.3%) cases, Pre-sliding group 2 (4.8%) cases. Complications leading to arthroplasty 6 cases, 6.7% (6/90, 95% CI: 1.4–11.9), 4 (8.3%) cases in the No-pre-sliding group and 2 (4.8%) cases in the Pre-sliding group (Table 4).

Comparison of the degree of femoral neck shortening at postoperative follow-up between the two groups (Fig. 2).

The occurrence of shortening was concentrated at 3 months postoperatively and essentially reached a stable state within 6 months, with less persistent shortening occurring after 6 months. In displaced femoral neck fractures, the mean postoperative follow-up shortening was less in the Pre-sliding group than in the Non-pre-sliding group at all time periods.

Fig. 3 illustrates a comparative case study of the application of the FNS in two patients with Garden type IV femoral neck fractures. The first patient (Panels A–C), Panel A displays the preoperative radiograph showing the fracture, Panel B displays the immediate postoperative image with a full 20 mm sliding space provided by the FNS, and Panel C reveals a significant shortening of the femoral neck after 6 months, with the FNS maintaining a reduced sliding space of about 5 mm. For the second patient (Panels D–F), Panel D presents the preoperative radiograph, Panel E shows the postoperative configuration with a limited 5 mm sliding space due to the FNS, and Panel F demonstrates a mild shortening of the femoral neck at the 6-month mark, with less than 5 mm (Fig. 3).

6. Discussion

The high incidence of complications after fixation of FNF imposes an incalculable psychological and economic burden on patients and society. In this study, we found that the incidence of severe femoral neck shortening (>10 mm) after FNS fixation was higher in unstable FNF (displaced fractures: Garden type III and IV) than in stable FNF (no-displaced fractures: Garden type I and II); the use of the pre-sliding technique in displaced femoral neck fractures can reduce the degree of shortening and the incidence of severe shortening, and improve the postoperative Harris hip Score.

6.1. Incidence and characteristics of femoral neck shortening after FNS fixation of femoral neck fractures

FNS has been used in clinical practice for a relatively short period of time, and there are many reports of complications such as fracture nonunion and femoral head necrosis, but there are fewer reports of postoperative femoral neck shortening. Femoral neck shortening is a relatively common complication in the early stage of the process, with an incidence rate of 8.3–10.0% reported in the literature [16,17], and there are also reports that the incidence rate of femoral neck shortening after fixation ranges from 28% to 39.1% [8,18], and there is a wide variation in the incidence rates reported in different studies. To clarify the differences in the incidence of femoral neck shortening after FNS fixation for different fracture types, this study was analyzed according to different fracture types and found that there were no cases of moderate or severe shortening in no-displaced femoral neck fractures, and the incidence of moderate and severe shortening in displaced FNF was 29.2% and 58.2%, and a total of 87.5% (21/24) of displaced FNF had shortening greater

Table 2
Comparison of fracture healing time, shortening and Harris score between Pre-sliding group and No-pre-sliding group.

Group		No-pre-sliding (n = 48)	Pre-sliding (n = 42)	$t/Z/X^2$ value	*P* value
Fracture healing time (weeks) M(Q1,Q3)	Median (Q1–Q3)	8.0 (6.0,10.0)	6.0 (6.0,10.0)	−0.941	0.347
Shortening classification (1 year)	0–5 mm(n)	27 (56.3%)	35 (83.3%)	8.606	0.014
	> 5 , ≤10 mm(n)	7 (14.5%)	4 (9.5%)		
	> 10 mm(n)	14 (29.2%)	3 (7.2%)		
Shortening distance (1 year)	mm	6.5 ± 6.4	3.9 ± 3.4	2.501	0.015
Harris score (1 year) M(Q1,Q3)	Median (Q1–Q3)	88.7 (79.8 , 93.5)	94.8 (87.7 , 96.9)	−3.099	0.002

Table 3
Comparison of the degree of shortening with and without the Pre-sliding technique for different fracture types.

Group	Shortening	No-pre-sliding (n = 48)	Pre-sliding (n = 42)	X^2 value	*P* value
Nondisplaced (Garden I and II) (n = 35)	0–5 mm(n)	24 (100.0%)	11 (100.0%)	–	1
	> 5 , ≤10 mm(n)	0 (0.0%)	0 (0.0%)		
	> 10 mm(n)	0 (0.0%)	0 (0.0%)		
Displaced (Garden III and IV) (n = 55)	0–5 mm(n)	3 (12.5%)	24 (77.4%)	23.763	< 0.001
	> 5 , ≤10 mm(n)	7 (29.2 %)	4 (12.9%)		
	> 10 mm(n)	14 (58.3%)	3 (9.7%)		

Table 4
Difference in occurrence of treatment-related complications at 1 year.

Complications	No-pre-sliding (n = 48)	Pre-sliding (n = 42)	Total (N = 90)	
			n	% (95% CI)
Deep wound infection	0 (0.0%)	0 (0.0%)	0	–
Cut-out	1 (2.1%)	1 (2.4%)	2	2.2 (0–5.3)
Implant loosening	1 (2.1%)	3 (7.1%)	4	4.4 (0.1–8.8)
Implant breakage/bending	0 (0.0%)	0 (0.0%)	0	–
Delayed union	3 (6.3%)	2 (4.8%)	5	5.6 (0.7–10.4)
Non-union	0 (0.0%)	0 (0.0%)	0	–
Femoral head collapse	4 (8.3%)	2 (4.8%)	6	6.7 (1.4–11.9)
Complications leading to arthroplasty	4 (8.3%)	2 (4.8%)	6	6.7 (1.4–11.9)

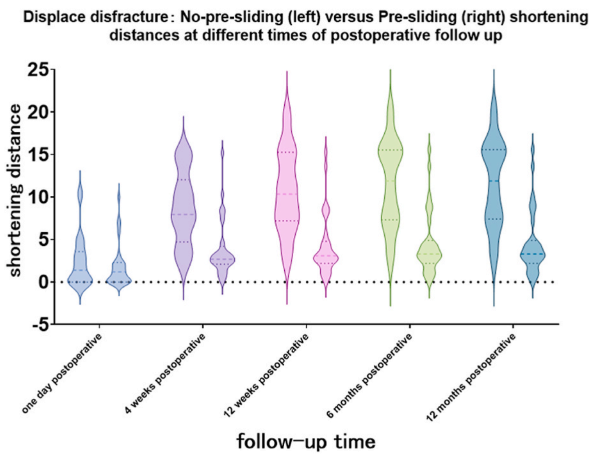

Fig. 2. Comparison of the degree of postoperative shortening of displaced femoral neck fractures using FNS fixation with or without the Pre-sliding technique.

than 5 mm. This suggests that displaced FNF may be a risk factor for shortening after FNS fixation, which is consistent with previous multifactorial analyses suggesting that displaced fracture, cortical comminution, and quality of reduction are risk factors for shortening [19,20]. The incidence of postoperative shortening of displaced FNF is high, and it is necessary to implement preventive strategies to minimize femoral neck shortening before surgery to achieve the goals of reducing complications and improving hip function.

The analysis showed that the occurrence of shortening was concentrated at 3 months postoperatively and basically reached a stable state within 6 months, with less persistent shortening occurring after 6 months. The mean shortening distance at 1 year postoperatively was (6.5 ± 6.4) mm, which was similar to previous reports of mean shortening in the range of 4.9 mm–8.4 mm, and seemed to be consistent with no progression of results at 3 months [17,21,22]. The reason may be due to the shortening caused by resorption and plastic modification of the fracture during fracture healing, and secondly, the excessive shortening of the affected limb combined with cortical comminution of the fracture and bone defect due to irrational weight bearing. According to the manufacturer's operating guidelines, the sliding groove of the FNS is favorable for fracture compression to promote healing, but excessive shortening in displaced fractures leads to a significantly higher incidence of severe shortening, and preventive measures should be taken in the early postoperative period, such as improving the anti-shortening ability of the FNS, reducing the sliding distance, and avoiding early weight bearing.

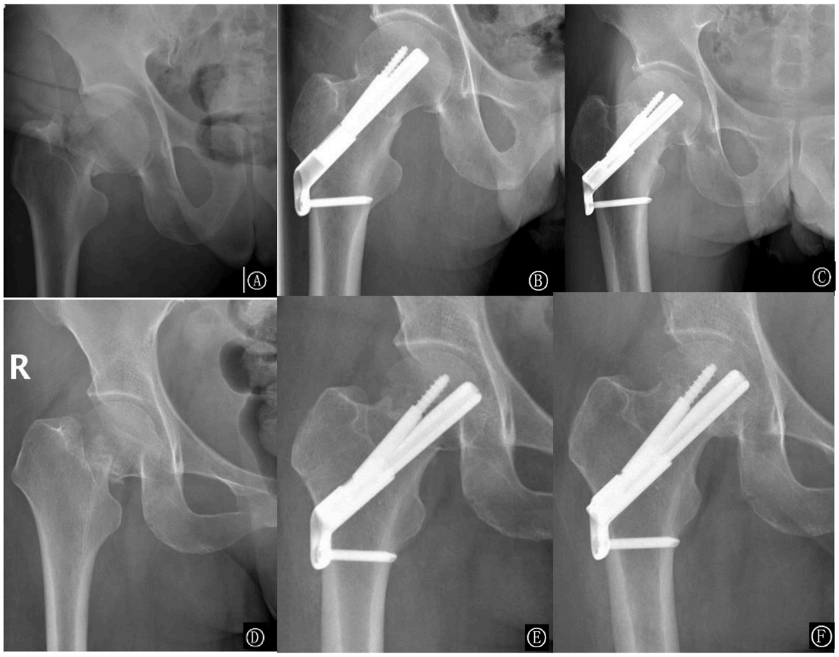

Fig. 3. A Male patient, 53 years old, preoperative orthopedic hip joint showing right femoral neck fracture (Garden type IV); B postoperative orthopedic hip joint with unrestricted FNS sliding space (20 mm); C 6 months postoperatively, the femoral neck is severely shortened, and the FNS still has a sliding space of about 5 mm, D Female patient, 58 years old, preoperative hip joint orthosis shows right femoral neck fracture (Garden type IV); E postoperative hip joint orthosis with FNS sliding space limiting sliding space (about 5 mm); F 6 months postoperatively, femoral neck is mildly shortened (shortening <5 mm).

6.2. Effects of shortening of the femoral neck

Femoral neck shortening results in hip abductor shortening, decreased eccentricity, hip function, and gait [23,24]. Yu et al. [25] found that with increasing femoral neck shortening, peak acetabular stress increased, load distribution became uneven, and hip mobility decreased. It was hypothesized that shortening may play a role in femoral head necrosis [26]. Zlowodzki et al. [13] found that those with femoral neck shortening <5 mm had an increased likelihood of postoperative pain, claudication, and use of crutches compared with those with shortening ≥5 mm, and also found that the incidence of moderate to severe shortening (≥5 mm) after cannulated screw fixation was 31%. A grading system based on the degree of shortening was proposed: Mild, moderate, and severe, with mild shortening having the least impact on function. Then, a survey of physicians revealed that 83% of respondents believed that postoperative femoral neck shortening was common [27], and in previous studies of severe shortening 40% of patients complained of a shorter lower limb, 30% of patients used shoe inserts for heightening, and the patients had a decrease in gait speed [1.1 m/s (normal gait speed is 1.3–1.5 m/s)], as well as a decrease in adductor muscle strength of approximately 20 N [28,29]. Our analysis showed that the use of the pre-sliding technique against shortening in displaced FNF reduced the mean distance of shortening at 1 year post-operatively ($t = 2.501$, $p = 0.015$) and improved Harris Hip Scores ($Z = -3.099$,$p = 0.002$). A 2019 FAITH study [30] found that more than one third of femoral neck fracture patients had moderate or severe shortening (>5 mm) postoperatively, while increased femoral neck shortening was associated with decreased hip function. Slobogean et al. [31] found that 13% of patients had severe shortening, and shortening led to a functional decrease in Harris Hip Scores. The mean difference in HHS was −9.9 ($p = 0.025$). Therefore, it is important to consider how to avoid moderate and severe shortening when fixating femoral neck fractures with the FNS.

6.3. Causes and prevention of femoral neck shortening after FNS fixation

In this study, the incidence and degree of shortening were found to be higher in displaced FNF than in no-displaced FNF, which may be attributed to the fact that displaced FNF often occur in high-energy injuries combined with destruction of surrounding soft tissues and comminution of the cortex, which places higher demands on internal fixation in terms of resistance to inversion, rotation, and shortening. Although FNS has stronger anti-rotation and anti-inversion capabilities than cannulated screw, it must rely on the contact of the fracture to provide anti-shortening reaction force, and the reduction of the effective contact surface of the fracture due to cortical comminution and poor reduction will lead to an increase in the incidence of shortening. The main risk factors for shortening after FNS fixation include the combination of cortical comminution, displaced fracture, and the quality of reduction [19,32,33]. At the same time, the FNS reserved 20 mm of sliding space, and the resistance to shortening was based on the cortical contact of the fracture, which was prone to over shortening in the postoperative period due to poor fracture reduction and cortical comminution that prevented the formation of cortical contact. Although the FNS has greater resistance to rotation and collapse, and at the same time, during weight bearing, repeated compression of the fracture, and resorption of the fracture during the healing process, the patients were more prone to shortening of the femoral neck in the early postoperative period. As reported in this study and other literature, the occurrence of shortening was mainly concentrated within 3 months postoperatively [8]..

How can femoral neck shortening be prevented after FNS fixation of displaced FNF? First, anatomic reduction, especially to avoid postoperative residual inversion, posterior tilt and rotational deformity of the femoral head, to improve the stability of the fracture, like other fixation methods, non-anatomic reduction is a risk factor for shortening of the femoral neck fracture after FNS fixation. Second, to avoid early weight bearing, 3 months is the risk period for shortening, for displaced FNF, especially in combination with cortical comminution and using FNS fixation, we recommend 20 kg weight bearing of the injured lower limb in 3 months and gradually resume weight bearing according to the healing of the fracture. Third, improve the anti-shortening ability of internal fixation, for example, add a screw to combat shortening, and reduce the reserved sliding space, for example, pre-sliding technique.

6.4. Pre-sliding technique

The pre-sliding technique is not limited by the 5 mm distance between different FNS types, and by selecting a longer implant type based on the measured length, the screw can be inserted deeper, which reduces the TAD value and improves stability. Finite element analysis studies found that the fracture gap and sliding were reduced by 14% and 12%, respectively, after using the pre-sliding technique under walking load [9,10]. Second, the pre-sliding space is not limited by 20 mm, and the sliding distance can be reserved according to the need, which reduces the incidence of severe postoperative shortening. We analyzed and found that the average shortening distance after using the pre-sliding technique was reduced from 6.5 mm to 3.9 mm, a reduction of about 40%, which is useful in preventing postoperative shortening in displaced FNF. We recommend the use of the pre-sliding technique to prevent postoperative femoral neck shortening in displaced FNF.

7. Conclusion

In conclusion, the incidence of severe femoral neck shortening after FNS fixation is higher in unstable femoral neck fractures than in stable femoral necks; the use of the Femoral Neck System pre-sliding technique in displaced femoral neck fractures prevents femoral neck shortening in the postoperative period.

8. Limitation

This study was limited by the retrospective nature of the study, data recall bias and selective bias; the brief follow-up period, and necrosis and collapse of the femoral head after FNF need to be confirmed by a longer follow-up study; the low number of cases in the two groups; and the lack of comparison with cannulated screw treatment and other internal fixation, making it impossible to determine whether FNS is an independent risk factor for shortening.

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Ethics approval and consent to participate

The study was approved by the Medical Ethics Committee of Trauma Center (2021185).

Consent for publication

Not applicable.

Data availability statement

All data generated or analyzed during this study are included in this article.

CRediT authorship contribution statement

Dongze Lin: Writing – original draft, Funding acquisition, Formal analysis, Data curation, Conceptualization. **Fugui Zhu:** Investigation, Formal analysis, Data curation. **Peisheng Chen:** Software, Resources, Project administration. **Chaohui Lin:** Software, Resources, Project administration, Methodology. **Bin Chen:** Project administration. **Ke Zheng:** Supervision, Software, Resources, Data curation, Conceptualization. **Shunze Zheng:** Visualization, Validation, Investigation, Data curation. **Fengfei Lin:** Writing – review & editing, Visualization, Funding acquisition.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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