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Fracture classification and coronal plane position of bolt may affect the prognosis after femoral neck system (FNS) surgery for femoral neck fractures

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Abstract

Purpose This study aims to investigate the risk factors for postoperative complications following Femoral Neck System (FNS) fixation in young patients with femoral neck fractures (FNFs).

Methods We retrospective analyzed 133 patients with FNFs who underwent FNS fixation between May 2021 and October 2023. Potential risk factors that may affect the results included age, gender, body mass index (BMI), Pauwels classification, Garden classification, fracture anatomical classification, reduction method, reduction quality, coronal plane position of the FNS bolt. Postoperative complication data, including femoral head necrosis, nonunion, shortening of the femoral neck, fracture displacement, and screw cut-out, were collected. Multivariate logistic regression analysis was used to analyze different influencing factors.

Results A total of 133 FNFs patients were divided into a healing group (108 patients) and a failure group (25 patients). 25 patients (18.79%) had postoperative complications, including 8 cases of femoral head necrosis, 3 cases of nonunion, 3 cases of significant shortening of the femoral neck, and 7 cases of fracture displacement, 4 cases of screw cut-out; the remaining patients' fractures all healed. There were no statistical differences between the two groups in age ($P=0.746$), gender ($P=0.992$), BMI ($P=0.361$), Pauwels classification ($P=0.231$), fracture anatomical classification ($P=0.459$), reduction method ($P=0.383$). Garden classification significantly influenced postoperative complications, with the proportion of Garden type IV being significantly higher in the failure group than in the healing group (64% vs. 39.8%, $P=0.01$). Multivariate logistic regression analysis showed that coronal position of the FNS bolt and reduction quality were risk factors for postoperative complications. Subgroup analysis using logistic regression showed a positive correlation between coronal plane position of the FNS bolt and reduction quality with the occurrence of

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postoperative complications, with FNS positioned in the upper 1/3 and negative support being significant risk factors ($P < 0.01$; $P < 0.01$).

Conclusions FNS is an effective method for treating FNFs in young adults, but there is still a certain risk of failure. The Garden classification is an important evaluation indicator for postoperative complications, with a higher failure rate observed in type IV fractures. Coronal plane position of the FNS bolt and reduction quality are significant risk factors for failure after FNS surgery for FNFs.

Keywords Femoral neck system, Femoral neck fractures, Internal fixation failure

Most femoral neck fractures (FNFs) in young patients are caused by high-energy injuries, and internal fixation is used as a common treatment method [1, 2]. Femoral neck system (FNS), as a new internal fixation method for FNFs, has gradually gained popularity and application due to its minimally invasive and good stability. In short-term follow-up [3] and meta-analysis [4], FNS has shown superior clinical efficacy compared with multiple conventional cannulated screw (CCS) fixation in the treatment of young patients with FNFs.

Due to the unique anatomy of FNFs, the irregular rotational and shear forces at the fracture end, and the fragile blood supply to the femoral neck, the failure rate of internal fixation of FNFs is relatively high. Previous analyses of risk factors for postoperative internal fixation failure with FNS have shown that factors such as fracture displacement, reduction quality, and postoperative weight-bearing time influence the healing of FNFs [5, 6]. However, there is very little research on the effect of fracture classification (Pauwels, Garden, fracture anatomical classification) on postoperative complications with FNS. Because the effect of screw position of DHS and multiple screws on prognosis has been widely concerned, but the position of FNS in the internal femoral neck has not been concerned, so it is necessary to pay attention [7, 8]. However, no study has analyzed the relationship between the coronal plane position of FNS bolt on the femoral neck and postoperative complications.

Therefore, exploring the risk factors associated with postoperative complications after FNS is critical to improving its efficacy and success rate. This study aims to investigate the risk factors associated with postoperative complications after FNS surgery.

Materials and methods

Study design

This study was conducted at our orthopedic trauma center from May 2021 to October 2023. A series of young patients diagnosed with FNFs underwent FNS surgery. A retrospective study was conducted to evaluate the factors associated with postoperative complications after FNS surgery in patients with FNFs. This retrospective study was approved by the Ethics Committee of the Affiliated Dongnan Hospital of Xiamen University. Informed consent was obtained from all participants to participate in the study after full explanation of the study procedures. The present study is a retrospective review of medical data and the human research ethics committee of our institution stated to exempt it from formal ethical review according to the ethical principles laid forth by the Helsinki Declaration (No. 2022122901). Written consent of patients was not sought. No identifying information was recorded by the authors.

Inclusion and exclusive criteria

The subjects included in this study were all hospitalized in our orthopedic center and underwent FNS surgery. Inclusion criteria were as follows: ① patients diagnosed with FNFs; ② patients aged between 14 and 60 years; ③ patients with high postoperative compliance and who were followed up for at least 12 months; ④ patients who were able to walk independently or with assistance before the injury and did not have severe consciousness disorders. Exclusion criteria included: ① pathologic fractures, open fractures, multiple fractures; ② postoperative infections; ③ patients with conditions such as pre-existing femoral head necrosis, developmental hip dysplasia, severe hip arthritis leading to weakened or lost ambulation before injury; ④ long-term steroid use, alcohol abuse, smoking.

Surgical techniques, postoperative treatment, and rehabilitation programs

All FNS were purchased from DePuy Synthes (USA, Fig. 1). All surgeries were performed by a single orthopedic surgical team consisting of two senior surgeons with equivalent surgical proficiency. Surgical procedures followed the standard protocol [9]. Closed reduction was initially attempted in all cases, and patients who failed closed reduction underwent direct anterior approach-assisted open reduction. All patients followed the standardized postoperative rehabilitation protocol at our hospital's orthopedic center until discharge. Antibiotics were administered postoperatively to prevent infection, and radiographs of the limbs were taken on the first postoperative day after wound dressing changes. Low molecular weight heparin was administered from the second postoperative day to prevent deep vein thrombosis in the

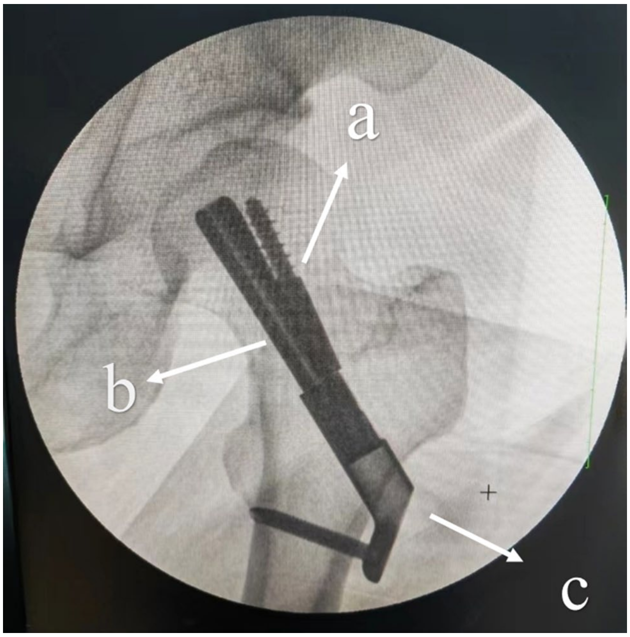

Fig. 1 FNS system. FNS consists of three parts: **a** circular, blunt, lockable anti-rotation screw; **b** circular blunt bolt; **c** plate and locking screw in an angle-stable structure

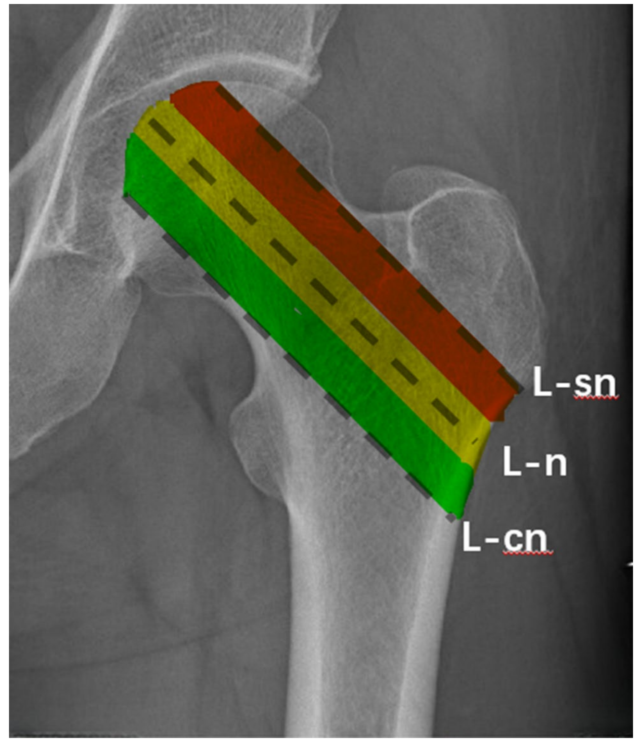

Fig. 2 Coronal plane position of the FNS bolt. Coronal section of the femoral neck is subdivided into three sections, designated as the upper, middle, and lower thirds. **L-n** The line serves as a reference line for the femoral head-neck axis; **L-cn** A reference line is established through the femoral calcar, which is parallel to the femoral head-neck central axis; **L-sn** A reference line is established parallel to the femoral head-neck central axis through the upper edge of the femoral neck. The region between L-cn and sn is subdivided into upper, middle, and lower thirds, with the subdivision occurring in a direction perpendicular to L-n

lower limbs. Passive joint function exercises and activities were started on the day after surgery. Subsequently, under the guidance of the surgical team, patients underwent a series of functional exercises to gradually increase the weight-bearing capacity of the affected limb. To reduce the incidence of femoral head necrosis, weight-bearing was avoided for two months postoperatively, followed by partial weight-bearing at three months postoperatively, with a gradual transition to full weight-bearing [5].

Patient assessment

Two external and independent investigators who were not involved in patient care were responsible for data collection. Baseline demographic data were collected, including age, sex, BMI, Pauwels classification, Garden classification, and anatomic classification of the fracture site. Reduction method, coronal plane position of the FNS bolt, reduction quality, and postoperative complications were recorded.

BMI was calculated as weight (kg) divided by the square of height (m). Fracture types were assessed using preoperative radiographs and computed tomography (CT) scans. Analysis of imaging data was performed independently by an experienced orthopedic surgeon and an experienced radiologist. All FNFs were radiographically classified according to the Garden classification [10], the Pauwels system [11], and the anatomic classification of the fracture. The Pauwels angle was defined as the angle between the fracture line and the horizontal plane and was measured before surgery [12]. Based on the anatomic location of the fracture, FNFs were classified as subcapital, transcervical, cervicotrochanteric, and basicervical types. Due to the retrospective nature of the study, it was not possible to ensure that all anteroposterior (AP) and lateral radiographs were standardized.

Coronal plane position of the FNS bolt: Refer to the nail placement for treating femoral neck fractures with DHS [7, 13]. On the AP radiographs of the affected limb, locate the center of the femoral head and the midpoint of the narrowest part of the femoral neck in the anteroposterior view. Draw a line connecting these two points to establish the femoral head-neck axis reference line (labeled L-n). Establish a line parallel to L-n through the femoral calcar (L-cn). Establish a line parallel to L-n at the top of the femoral neck (L-sn). Divide the area between L-cn and L-sn into upper, middle and lower thirds along a direction perpendicular to L-n (Fig. 2) and record the position of the FNS bolt (Fig. 1b). For cases where FNS bolts span two regions, we calculate the proportion of the bolt at the proximal end of the fracture line in each region during grouping, and then assign it to the group of the region with the majority.

Reduction quality: Fracture reduction is classified into anatomic and non-anatomic reduction based on the position of the fracture end on postoperative radiographs. According to Gotfried's definition of non-anatomic reduction for femoral neck fractures [14], negative support is defined as the position of the inner cortex of the femoral neck head fragment on the outer cortex of the distal femoral shaft, while positive support is defined as the position of the inner cortex of the femoral neck head fragment on the inner cortex of the distal femoral shaft.

Postoperative complications are defined as femoral head necrosis, femoral neck shortening, nonunion, fracture displacement, and screw fracture [6, 15]. On X-rays, femoral head necrosis is defined by the early appearance of local cystic changes and uneven density around the cystic area and the late appearance of femoral head deformities such as incomplete margins, osteolytic or flat shapes, partial disappearance of trabecular structures, uneven bone density, narrowing or disappearance of the gap between the acetabulum and the femoral head [16]. Nonunion is defined as incomplete fracture healing at 9 months postinjury with no radiographic evidence of progression within the previous 3 months. Femoral neck shortening is measured according to the method described above [17], whereby shortening in the longitudinal axis of the femoral neck is measured using X-rays taken intraoperatively or on the first postoperative day and the last follow-up radiograph, with FNS devices measuring shortening through the lateral protrusion of the anti-rotation screw. All X-rays are corrected for magnification using the ratio of the screw diameter on the X-ray to the known screw diameter. Three measurements are taken per subject, averaged, and more than 5 mm is considered femoral neck shortening [18]. Screw cut-out is defined as cut-out of the bolt-and-plate or anti-rotation screw or loosening of the locking screw [6].

Statistical analysis

Continuous variables are expressed as mean±standard deviation, and categorical variables are expressed as absolute values and percentages. All data were analyzed using the Wilcoxon rank sum test (Mann-Whitney U test). Differences in continuous variables were tested using the two-tailed Student's t-test, and differences in categorical variables were assessed using the Pearson $\chi 2$ test or Fisher's exact test where appropriate. Statistical analysis was carried out using SPSS version 21.0 statistical software (SPSS Inc. Chicago, IL, USA). Multifactor logistic regression analysis was used to analyze different influencing factors, calculating odds ratios and 95% confidence intervals. $P<0.05$ was considered statistically significant (see Fig. 3).

Results

Patients' characteristics

From May 2021 to October 2023, a total of 149 consecutive patients diagnosed with FNFs underwent FNS surgery at our hospital. Sixteen cases were excluded based on inclusion and exclusion criteria, leaving 133 patients who met the inclusion criteria, with an average age of 44.88±13.15 (range 14–82) years, analyzed (two groups: failure group [$n=25$] and healing group [$n=108$]) (Table 1). All patients were followed up for over a year, with a mean follow-up time of (16.2±1.5) months. The average BMI was 22.6±2.5 kg/m2. The male-to-female ratio was 85:48. There were no statistically significant differences between the two groups in terms of age ($P=0.746$), gender ($P=0.992$), and BMI ($P=0.361$) (Table 1).

Complications after FNS surgery

Among the 133 patients, 25 patients (18.79%) experienced fracture healing-related postoperative complications after FNS surgery, including 8 cases of femoral head necrosis, 3 cases of nonunion, 3 cases of significant shortening of the femoral neck, and 7 cases of fracture displacement, 4 cases of screw cut-out; the remaining patients' fractures all healed (Table 2).

Comparison of radiographic data

The differences between the two groups in Pauwels classification ($P=0.23$), fracture anatomical classification ($P=0.46$), and reduction method ($P=0.38$) were not statistically significant. Subsequently, the proportion of Garden type IV fractures in the failure group was significantly higher than in the healing group (64% vs. 39.8%, $P=0.01$), while the proportions of Garden type II and III fractures were lower in the failure group compared to the healing group (4% vs. 25%; 32% vs. 35.2%, $P=0.01$; Table 3). The proportion of FNS position in the upper and middle 1/3 was significantly higher in the failure group compared to the healing group (28% vs. 0.9%; 20% vs. 7.4%; $P<0.01$), while the proportion in the lower 1/3 was significantly lower in the failure group compared to the healing group (52% vs. 91.7%; $P<0.01$; Table 4). The proportion of anatomical reduction in the failure group was significantly lower than in the healing group (16% vs. 73.1%; $P<0.01$), with higher proportions of positive and negative supports compared to the healing group (32% vs. 13%; 52% vs. 13.9%; $P<0.01$; Table 4).

Multivariate logistic regression analysis and subgroup analysis

Multivariate logistic regression analysis determined that the coronal plane position of the FNS bolt ($P<0.01$) and reduction quality ($P<0.01$) were statistically significant risk factors, while Garden classification was not a

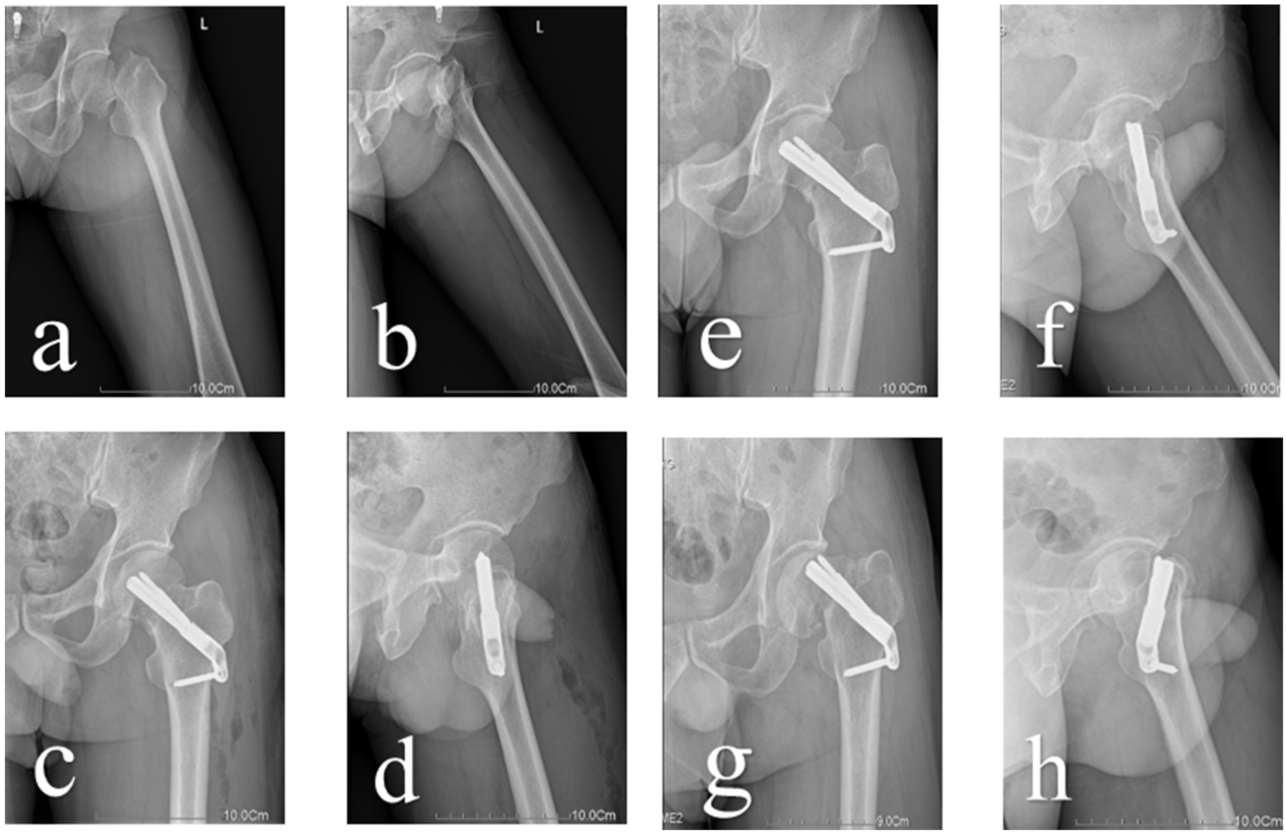

Fig. 3 Male patient, 51 years old, Garden IV FNF. **a**, **b** preoperative AP and lateral X-rays; **c**, **d** positive support shown on the 2nd day after FNS surgery; **e**, **f** X-ray at 3 months post FNS surgery showing poor fracture healing; **g**, **h** X-ray at 3 months post FNS surgery showing internal fixation failure, fracture displacement, nonunion, and screw cut-out

Table 1 Demographic details of patients

Characteristics	Failure group (*n* = 25)	Healing group (*n* = 108)	t/X^2 value	*P* value
Age	34.8 ± 5.4	35.2 ± 5.6	1.455	0.746[a]
Gender				0.992[b]
Male	16(64%)	69(63.9%)	<0.01	
Female	9(36%)	39(36.1)		
BMI (kg/m^2)	22.3 ± 2.7	22.8 ± 2.4	0.917	0.361[a]

BMI Body mass index, no. Number of patients, SD Standard deviation

[a] Analyzed using independent sample t test

[b] Analyzed using chi-square test

Table 2 Complications after FNS surgery

Postoperative complications	(*n*, %)
Femoral head necrosis	8(32%)
Nonunion	3(12%)
Neck shortening	3(12%)
fracture displacement	7(28%)
Cut-out	4(16%)

Table 3 Comparison of radiographic data between the two groups

Characteristics	Failure group (*n* = 25)	Healing group (*n* = 108)	U value	*P* value
Pauwels classification			1157	0.231[a]
I	3 (12%)	24 (22.2%)		
II	11 (44%)	47 (43.5%)		
III	11 (44%)	37 (34.3%)		
Garden classification			934	0.01
II	1 (4%)	27 (25%)		
III	8 (32%)	38 (35.2%)		
IV	16 (64%)	43 (39.8%)		
Fracture anatomical classification			1228	0.459
Subcapital	10 (40%)	37 (34.3%)		
Transcervical	6 (24%)	10 (9.3%)		
Cervicotrochanteric	4 (16%)	47 (43.5%)		
Basicervical	5 (20%)	14 (12.9%)		

[a] Analyzed using Mann-Whitnery U test

statistically significant risk factor (P=0.07, Table 5). Subgroup analysis indicated that the coronal plane position of the FNS bolt and reduction quality were positively correlated with postoperative complications, with OR values of 4.5 and 257 for the middle and upper 1/3 compared to the lower 1/3 of the femoral neck, respectively. coronal plane position of the FNS bolt in the upper 1/3 was a significant risk factor (P<0.01). The OR values for positive

Table 4 Comparison of surgery between the two groups

Characteristics	Failure group (*n* = 25)	Healing group (*n* = 108)	U/F value	*P* value
Coronal position of the FNS bolt			789	<0.01[a]
Upper 1/3	7(28%)	1 (0.9%)		
Middle 1/3	5(20%)	8 (7.4%)		
Lower 1/3	13 (52%)	99 (91.7%)		
Reduction quality			568	<0.01
Anatomical reduction	4(16%)	79(73.1%)		
Positive support	8(32%)	14(13%)		
Negative support	13(52%)	15(13.9%)		
Reduction method			0.761	0.383[b]
Open reduction	22(88%)	87(80.6%)		
Closed reduction	3(12%)	21(19.4%)		

[a] Analyzed using Mann-Whitney U test

[b] Analyzed using Fisher's exact test

and negative support compared to anatomical reduction were 31.3 and 53.1, respectively. Negative support was a significant risk factor ($P < 0.01$, Table 6).

Discussion

The occurrence and severity of postoperative complications after FNFs treated with FNS (e.g., femoral head necrosis, nonunion, shortening of the femoral neck, fracture displacement, and screw cut-out) are closely related to the quality of fracture reduction and internal fixation. This study found that poor reduction quality is one of the risk factors for internal fixation failure after FNS surgery for FNFs, which is consistent with the results of Zhang [5], indicating the crucial importance of reduction quality in reconstructing fracture stability. Suboptimal fracture reduction may lead to issues such as poor fracture healing, fracture instability, or inadequate blood supply to the fracture site, thereby increasing the risk of postoperative complications. A finite element analysis on FNS demonstrated that for the reduction of FNFs, negative support is more likely to cause shortening of the femoral neck. The presence of the femoral calcar makes the medial and posterior aspects of the femoral neck crucial for fracture stability. When the femoral neck is in anatomical reduction or positive support, the pressure from body weight can effectively transmit downwards through the femoral calcar, providing a certain compressive effect on the fracture site [19]. Furthermore, due to the lack of effective pressure transmission, negative support can subject the FNS to greater shear forces, which may be a reason for the higher failure rate of negative support [20].

The coronal plane position of the FNS bolt is also one of the factors influencing fracture prognosis. When performing fracture reduction, selecting the appropriate position for FNS is crucial. In clinical practice, there is a consensus on the placement of the main screw in the lower part of the femoral neck in the coronal plane when treating FNFs with DHS. Wu [8] suggest that a slightly lower position for the lag screw is preferable; Parker [13] advocates for the lag screw to be placed centrally or slightly lower in the coronal plane; Thomas pointed out that the lower third of the femoral head-neck junction is the best position [7]. Currently, it is unclear whether placing FNS below the central axis of the femoral head-neck junction exhibits better biomechanical advantages similar to DHS. The fixation principle of FNS is similar to DHS, with a consensus on the placement of FNS bolt in the coronal plane at the center of the femoral neck. In this study, when FNS was placed in the upper, middle, and lower thirds, the postoperative internal fixation failure rates were 87.5% (7/8), 38.4% (5/13), and 11.6% (13/112) respectively. Multifactor logistic regression analysis showed that the position of the coronal plane position of the FNS bolt is a risk factor for postoperative

Table 5 Multivariate logistic regression analysis of risk factor for postoperative complications after FNS fixation

Variable	β	SE	Wald	OR	95%CR	*P* value
Garden classification	0.785	0.435	3.260	2.192	(0.935, 5.139)	0.071
Coronal position of the FNS bolt	2.193	0.515	18.138	8.964	(3.267, 24.594)	<0.01
Reduction quality	1.608	0.387	17.271	4.992	(2.339, 10.655)	<0.01

Table 6 Subgroup analysis of multivariate logistic regression

Variable	β	SE	Wald	Exp(B)/OR	95%CR	*P* value
Garden classification (II)			2.570			0.277
III	1.573	1.286	1.496	4.823	(0.388, 60.026)	0.221
IV	1.899	1.199	2.506	6.677	(0.636, 70.056)	0.113
Coronal position of the FNS bolt(Lower 1/3)						0.001
Middle 1/3	1.598	0.871	3.367	4.943	(0.897, 27.246)	0.067
Upper 1/3	5.552	1.522	13.310	257.771	(13.057, 5088)	<0.01
Reduction quality(Anatomical reduction)						0.002
Positive support	3.444	1.141	9.104	31.303	(3.343, 293.139)	0.003
Negative support	3.971	1.106	12.898	53.063	(6.074, 463.549)	<0.01

internal fixation failure (P<0.01). Possible reasons for this include: ① Compared to placement in the upper third of the femoral neck, when FNS is placed in the middle to lower third, stress distribution is more uniform and dispersed, with better conductivity, lower internal fixation Von Mises stress, making it less prone to deformation and fracture; ② When FNS is positioned in the lower third of the femoral neck, closer to the femoral calcar, the compressible volume of cancellous bone in the femoral head-neck region is smaller, providing stronger grip for internal fixation on the femoral head.

Due to the unique anatomical position and stress loading characteristics of the femoral neck, different types of fractures have always been a hot topic of research. Previous studies have only focused on the impact of fracture displacement on postoperative internal fixation failure with FNS, and there is limited research on the influence of fracture classification (Pauwels, Garden, fracture anatomical classification) on postoperative fracture related complications [6]. Several studies support Garden classification as one of the risk factors for avascular necrosis of the femoral head after internal fixation of FNFs [21]. In our study, Garden classification was identified as an important evaluation index for postoperative complications of FNFs with FNS (P = 0.01). In clinical practice, the Garden classification standard is commonly used to classify FNFs. From types I-IV, a higher classification indicates greater injury severity and displacement at the fracture end, with a corresponding decrease in end stability. More severe injury and poorer stability often indicate more severe vascular damage around the fracture end. Displaced fractures are usually associated with anatomic structural damage at the fracture end, which results in easier absorption of bone at the fracture end, leading to loss of medial cortical bone and poor bone support [22]. In addition, for Garden type IV FNFs, more traction and reduction are required during surgery, which can also increase soft tissue damage in the affected limb.

In the younger population, fractures are often caused by high-energy injuries that tend to have vertical fracture patterns. The greater the verticality of the fracture pattern, the greater the vertical shear stress on the fracture plane and internal platform, which is more likely to result in internal fixation failure and fracture displacement [23]. In particular, Pauwels Type III unstable fractures have a higher incidence of femoral neck shortening, nonunion, and femoral head avascular necrosis [24, 25]. However, the results of this study shows that there is no statistically significant difference in the Pauwels classification of fractures between patients with and without internal fixation failure. In vitro tests have confirmed [26, 27] that FNS can achieve both angular stability and sliding compression in the treatment of Pauwels type III femoral neck fractures, with biomechanical stability superior to that of CCS alone, CCS combined with a medial buttress plate, and DHS. Based on this, we believe that FNS has good angular stability and strong fixation can better resist shear forces at the fracture ends, reducing the incidence of postoperative internal fixation failure by converting shear forces into compressive forces, which is beneficial for fracture healing.

Study limitations

① The surgeries of the patients included in this study were performed by different surgeons within the same treatment group. Variations in surgical techniques and perioperative management may introduce confounding biases that could affect the prognostic outcomes; ② The Pauwels classification depends on the physician's subjective assessment of the horizontal line and the fracture line. In addition, changes in patient positioning during imaging may affect the accuracy of this assessment. Consequently, both the Pauwels classification and the fracture reduction quality assessment in this study may contain errors that affect the analysis results [28]; ③This study was a single-center retrospective study with selective bias. Meanwhile, the small number of enrolled patients could not provide enough information and may result sample bias.

Conclusions

FNS is an effective method for treating FNFs in young adults, but there is still a certain risk of failure. The Garden classification is an important evaluation indicator for postoperative complications, with a higher failure rate observed in type IV fractures. Coronal plane position of the FNS bolt and reduction quality are significant risk factors for failure after FNS surgery for FNFs.

Abbreviations

FNS	Femoral neck system
FNFs	Femoral neck fractures
BMI	Body mass index
CCS	Conventional cannulated screw
CT	Computed tomography
SPSS	Statistical Product and Service Solutions
DHS	Dynamic hip screws

Supplementary Information

The online version contains supplementary material available at https://doi.org/10.1186/s12893-024-02692-w.

Supplementary Material 1

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Author contributions

Guofeng Huang and Haihong Zhang designed the study, modified and approvedthe final version of the manuscript. Cong Zhang wrote the first draft of the manuscript. Haisen Hong, Zhenqi Ding, Zhangxin Chen, Zhenhua

Zheng collected, analyzed and interpreted the data. All authors have read and approved the manuscript.

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Data availability

All data supporting the findings of this study are available within the paper and its Supplementary Information. Statistical Result are provided in Supplementary material.

Declarations

Ethics approval and consent to participate

This study was performed in accordance with the Declaration of Helsinki as revised in 2008 and was authorized by the Ethics and research committee at TheAffiliated Dongnan Hospital of Xiamen University. Clinical trial number not applicable. Informed consent was obtained from all participants to participate in the study after full explanation of the study procedures.

Consent for publication

Not applicable, as no identifying personal information is included in this manuscript. All patients or their families signed the informed consent before surgery and provided the consent to publish and report individual clinical data.

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Competing interests

The authors declare no competing interests.

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References

1. Maiya S, Khan T, Grimer RJ, Carter SR, Tillman RM. The management of intracapsular fractures of the proximal femur. J bone Joint Surg Br Volume. 2001;83:618–9.
2. Kuan FC, Hsu KL, Lin CL, Hong CK, Yeh ML, Su WR. Biomechanical properties of off-axis screw in Pauwels III femoral neck fracture fixation: bicortical screw construct is superior to unicortical screw construct. Injury. 2019;50:1889–94. https://doi.org/10.1016/j.injury.2019.07.020.
3. Chung H, Kim Y, Kook I, Kwak JW, Hwang KT. Comparative short-term outcomes of femoral Neck System (FNS) and cannulated screw fixation in patients with femoral Neck fractures: a Multicenter Study. Clin Orthop Surg. 2024;16:184–93. https://doi.org/10.4055/cios23190.
4. Zhou Y, Li Z, Lao K, Wang Z, Zhang L, Dai S, Fan X. Femoral neck system vs. cannulated screws on treating femoral neck fracture: a meta-analysis and system review. Front Surg. 2023;10:1224559. https://doi.org/10.3389/fsurg.2023.1224559.
5. Zhang Y, Zhang X, Li C, Lin Y, Lv Y, Huang S, Wang B, Wang Y, Zhu Z. Prediction of hip joint function and analysis of risk factors for internal fixation failure after femoral Neck System (FNS). BMC Musculoskelet Disord. 2023;24:674. https://doi.org/10.1186/s12891-023-06805-z.
6. Chen L, Jiang JB, Ma H, Duan X, Chen JL. Factors associated with early failure of the femoral neck system (FNS) in patients with femoral neck fractures. BMC Musculoskelet Disord. 2023;24:912. https://doi.org/10.1186/s12891-023-06994-7.
7. Thomas AP. Dynamic hip screws that fail. Injury. 1991;22:45–6. https://doi.org/10.1016/0020-1383(91)90161-7.
8. Wu CC, Shih CH. Biomechanical analysis of the dynamic hip screw in the treatment of intertrochanteric fractures. Arch Orthop Trauma Surg. 1991;110:307–10. https://doi.org/10.1007/bf00443464.
9. Zhang YZ, Lin Y, Li C, Yue XJ, Li GY, Wang B, Wang YQ, Zhu ZQ. 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;14:686–93. https://doi.org/10.1111/os.13235.
10. Kazley JM, Banerjee S, Abousayed MM, Rosenbaum AJ. Classifications in brief: Garden classification of femoral Neck fractures. Clin Orthop Relat Res. 2018;476:441–5. https://doi.org/10.1007/s11999.0000000000000066.
11. Shen M, Wang C, Chen H, Rui YF, Zhao S. An update on the Pauwels classification. J Orthop Surg Res. 2016;11:161. https://doi.org/10.1186/s13018-016-0498-3.
12. Magone KM, Owen JK, Kemker BP, Bloom O, Martin S, Atkinson P. (2018) A model to evaluate Pauwels type III femoral neck fractures. Proceedings of the Institution of Mechanical Engineers Part H, Journal of engineering in medicine 232:310–7. https://doi.org/10.1177/0954411917752972
13. Parker MJ. Cutting-out of the dynamic hip screw related to its position. J bone Joint Surg Br Volume. 1992;74:625. https://doi.org/10.1302/0301-620x.74b4.1624529.
14. Gotfried Y, Kovalenko S, Fuchs D. Nonanatomical reduction of displaced subcapital femoral fractures (gotfried reduction). J Orthop Trauma. 2013;27:e254–259. https://doi.org/10.1097/BOT.0b013e31828f8ffc.
15. Slobogean GP, Sprague SA, Scott T, Bhandari M. Complications following young femoral neck fractures. Injury. 2015;46:484–91. https://doi.org/10.1016/j.injury.2014.10.010.
16. Wang T, Sun JY, Zha GC, Jiang T, You ZJ, Yuan DJ. Analysis of risk factors for femoral head necrosis after internal fixation in femoral neck fractures. Orthopedics. 2014;37:e1117–1123. https://doi.org/10.3928/01477447-20141124-60.
17. Su M, He Z, Huang N, Lin X, Fang K, Dai Z. Superior short-term outcomes of FNS in combination with a cannulated screw in treating femoral neck fractures. BMC Musculoskelet Disord. 2023;24:823. https://doi.org/10.1186/s12891-023-06959-w.
18. Stockton DJ, Lefaivre KA, Deakin DE, Osterhoff G, Yamada A, Broekhuyse HM, O'Brien PJ, Slobogean GP. Incidence, magnitude, and predictors of shortening in young femoral Neck fractures. J Orthop Trauma. 2015;29:e293–298. https://doi.org/10.1097/bot.0000000000000351.
19. Zhao G, Liu M, Li B, Sun H, Wei B. Clinical observation and finite element analysis of cannulated screw internal fixation in the treatment of femoral neck fracture based on different reduction quality. J Orthop Surg Res. 2021;16:450. https://doi.org/10.1186/s13018-021-02580-6.
20. Fan Z, Chen P, Yu X, Li X, Su H, Chen H, Yang B, Qi J, Wang H. Biomechanical study of femoral neck system for young patients with nonanatomically reduced femoral neck fractures: a finite element. BMC Musculoskelet Disord. 2023;24:54. https://doi.org/10.1186/s12891-022-06124-9.
21. Kim JW, Oh JK, Byun YS, Shon OJ, Park JH, Oh HK, Shon HC, Park KC, Kim JJ, Lim SJ. Incidence of avascular necrosis of the femoral Head after Intramedullary Nailing of femoral shaft fractures: a Multicenter Retrospective Analysis of 542 cases. Medicine. 2016;95:e2728. https://doi.org/10.1097/md.0000000000002728.
22. Ji J, Chen H, Yang B, Dong L, Wang M, Huang X. [Risk factors for osteonecrosis of femoral head after femoral neck fracture fixation with femoral neck system]. Zhongguo Xiu Fu Chong Jian Wai Ke Za Zhi = Zhongguo Xiufu chongjian waike zazhi = Chinese. J Reparative Reconstr Surg. 2023;37:162–7. https://doi.org/10.7507/1002-1892.202211004.
23. Li J, Yin P, Zhang L, Chen H, Tang P. Medial anatomical buttress plate in treating displaced femoral neck fracture a finite element analysis. Injury. 2019;50:1895–900. https://doi.org/10.1016/j.injury.2019.08.024.
24. Slobogean GP, Stockton DJ, Zeng BF, Wang D, Ma B, Pollak AN. Femoral neck shortening in adult patients under the age of 55 years is associated with worse functional outcomes: analysis of the prospective multi-center study of hip fracture outcomes in China (SHOC). Injury. 2017;48:1837–42. https://doi.org/10.1016/j.injury.2017.06.013.

25. 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;48:2189–93. https://doi.org/10.1016/j.injury.2017.08.017.
26. Schopper C, Zderic I, Menze J, Müller D, Rocci M, Knobe M, Shoda E, Richards G, Gueorguiev B, Stoffel K. Higher stability and more predictive fixation with the femoral Neck System versus Hansson Pins in femoral neck fractures Pauwels II. J Orthop Translation. 2020;24:88–95. https://doi.org/10.1016/j.jot.2020.06.002.
27. Teng Y, Zhang Y, Guo C. Finite element analysis of femoral neck system in the treatment of Pauwels type III femoral neck fracture. Medicine. 2022;101:e29450. https://doi.org/10.1097/md.0000000000029450.
28. 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;46:1969–74. https://doi.org/10.1016/j.injury.2015.06.016.

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