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Research article

Comparison of three different internal fixation methods in the treatment of femoral neck fracture

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ABSTRACT

Objective: This study aimed to assess the efficacy of three different fixation methods in treating femoral neck fractures in young patients.
Methods: A retrospective analysis was conducted on 35 young patients with femoral neck fractures who underwent surgical treatment. Among them, 16, 12, and 7 patients underwent fixation with three cannulated compression screws (3CS), the femoral neck system (FNS), and the compound compression system (CCS), respectively. Data, including fracture classification, injury-to-surgery time, surgery duration, intraoperative blood loss, fluoroscopy instances, fracture healing time, complications, and Harris score at the final follow-up, were collected and analyzed to compare clinical outcomes among the three fixation methods.
Results: All patients were followed for at least 6 months, exhibiting no significant differences in age, gender, injury side, fracture type, or injury-to-operation time among the three groups ($P > 0.05$). The FNS and CCS groups exhibited shorter operation durations and fewer intraoperative fluoroscopy instances compared to the 3CS group ($P < 0.01$). Despite the minimally invasive nature of 3CS, the FNS and CCS groups experienced higher intraoperative blood loss ($P < 0.01$). During follow-up, only one patient with 3CS fixation developed nonunion. Additionally, patients treated with 3CS demonstrated a higher incidence of femoral head necrosis and severe femoral neck shortening than the FNS and CCS groups. Excluding patients with combined nonunion, no significant difference in mean fracture healing time was observed among the three groups ($P > 0.05$). At the last follow-up, the FNS and CCS groups showed higher Harris scores ($P < 0.05$).
Conclusions: Both FNS and CCS are effective internal fixation systems for the treatment of femoral neck fractures in young patients, yielding more satisfactory clinical functional outcomes than 3CS. Comparatively, the CCS system presents a higher risk of iatrogenic rotation of the proximal fracture segment. Therefore, we advocate the insertion of two to three 2.5 mm Kirschner wires from the upper edge of the femoral neck along the axial direction before CCS lag screw insertion to resist iatrogenic rotational stress.

1. Introduction

With the rapid growth of the population, and aging population, the incidence of hip fractures is escalating [1,2]. Among these,

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fractures of the femoral neck constitute approximately 50 % of cases [3]. Hip arthroplasty, recognized as the standard treatment for displaced femoral neck fractures in the elderly, facilitates early weight-bearing and yields satisfactory long-term outcomes [4]. For young patients with femoral neck fractures, the preferred treatment involves reduction and internal fixation, offering the advantage of preserving the autogenous femoral head [5]. However, the existing literature reveals a 9.3 % rate of fracture nonunion and a high incidence, ranging from 10 % to 30 %, of femoral head necrosis [6,7]. These complications entail substantial direct costs due to extended hospitalization and rehabilitation. Moreover, they contribute to adverse outcomes such as disability and depression, posing a significant socioeconomic burden [8]. Consequently, the selection of appropriate internal fixation methods for treating femoral neck fractures and improving prognosis has become a crucial focus in clinical research.

Currently, the three cannulated compression screws (3CS) and Dynamic Hip Screw (DHS) remain the primary internal fixation implants employed in young individuals with femoral neck fractures [9]. However, numerous studies have reported a high failure rate associated with 3CS fixation, leading to complications such as screw loosening, femoral head necrosis, femoral neck shortening, and suboptimal hip functional recovery, indicating certain limitations [10–12]. DHS fixation offers enhanced stability against bending and shear forces. Nevertheless, the technique necessitates extensive surgical exposure, which involves significant bone removal and soft tissue damage [13]. In recent years, two structurally similar internal fixation devices, the Femoral Neck System (FNS) and Compound Compression System (CCS), have emerged for treating femoral neck fractures in young patients (Fig. 1). These devices effectively combine the stability provided by the DHS with the minimally invasive characteristics of the 3CS, offering enhanced treatment options. Research has demonstrated that FNS, due to its rotational stability, angular stability, dynamic fixation, and minimally invasive properties, is one of the optimal treatment choices for femoral neck fractures [14,15]. Conversely, there are no clinical reports available for CCS, and its clinical efficacy compared to 3CS fixation and FNS remains unclear. This study aims to assess the efficacy of FNS, CCS, and 3CS in young patients with femoral neck fractures, analyzing and comparing the stability and incidence of complications associated with these three internal fixation methods.

2. Clinical data and methods

2.1. Clinical data

With the approval of our hospital's ethics review committee, we retrospectively selected clinical data from young patients admitted to Ningde Traditional Chinese Medicine Hospital with femoral neck fractures between January 2018 and February 2022. The study included 35 patients with closed femoral neck fractures who underwent surgical treatment. The mean age of all patients was 45 $\pm$ 13 years (range: 13–62 years), comprising 19 males and 16 females. Among these, 16, 12, and 7 cases were treated with 3CS, FNS, and CCS, respectively.

Inclusion criteria comprised a diagnosis of femoral neck fracture through imaging, non-elderly status (age $<$65 years), absence of medical diseases, no history of prolonged alcohol or glucocorticoid use, complete follow-up, and signed informed consent. Exclusion criteria encompassed pathological fracture, old femoral neck fracture, conservative treatment, and multiple traumas.

2.2. Surgical procedures

After successful anesthesia, patients were positioned on an orthopedic traction table for traction reduction of the fracture end, confirmed by C-arm fluoroscopy. The radiographic criteria for satisfactory reduction of fractures are as follows: On anteroposterior

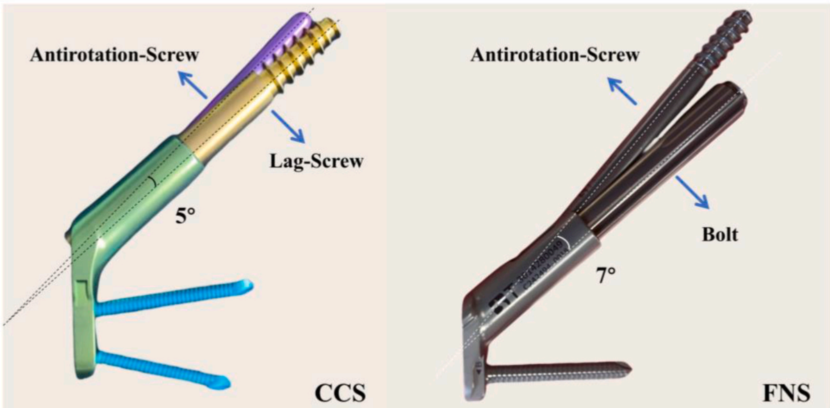

Fig. 1. The difference between CCS and FNS.
CCS: The lag screw had a diameter of 10.5 mm (including the thread). The antirotation screw, designed as a smooth rod, had a diameter of 6.0 mm, and the crossing angle between the two screws was 5°. CCS enables a postoperative sliding compression distance of 15 mm.
FNS: The power rod had a smooth design with a diameter of 10 mm, while the antirotation screw had a threaded design with a diameter of 6.5 mm. The two screws were positioned at an angle of 7° to each other. FNS can achieve a postoperative sliding compression distance of 20 mm.

(AP) radiographs, no varus angulation of the fracture fragments should be shown, the fracture displacement should be limited to less than or equal to 2 mm (mm), and angular deformity should be measured to no more than 15°. On lateral radiographs, fracture displacement should not be allowed to exceed 2 mm. A maximum of 20° of anterior angulation and 10° of posterior angulation are permitted [16].

2.3. Cannulated compression screw

Using a cannulated compression screw technique, three guide needles were transdermally inserted 2.5–4 cm below the greater trochanter of the femur. One guide pin is placed at the distal end of the greater trochanter directed towards the middle of the femoral moment. The other two guide pins are positioned at the anterior and posterior borders of the cortical bone at the proximal end of the greater trochanter, maintaining proximity to the cortical bone. The needles were directed towards the femoral head, penetrating up to 0.5 cm below the cartilage surface, forming an inverted triangle distribution. Subsequent fluoroscopy with a C-arm machine verified the adequacy of depth, position, and angle of the guide needles. Upon verification, three cannulated compression screws of suitable diameter and length are employed to secure the fracture (Fig. 2).

2.4. Femoral neck system

The fracture end was initially secured with one antirotation wire. Following this, a 5 cm incision was made on the lateral side of the upper femur, exposing the lateral wall of the greater trochanter. Utilizing the FNS guide, the guide pin of the femoral neck power rod was carefully inserted into the femoral neck, extending to 0.5 cm below the cartilage surface of the femoral head. Fluoroscopy confirmed the precise positioning of the guide pin. In AP radiographs, the guide pin should appear in the middle to lower third of the femoral neck, whereas in lateral radiographs, it should be centrally located within the femoral neck. After measuring the depth, the hole was expanded, and the power rod was threaded through the guide pin, with subsequent installation of the lateral plate. The distal locking screw and proximal anti-rotation screw were then sequentially screwed in according to the provided guide. Following this step, the guide was removed, and the hip was manipulated to verify the secure fixation of the fracture (Fig. 3).

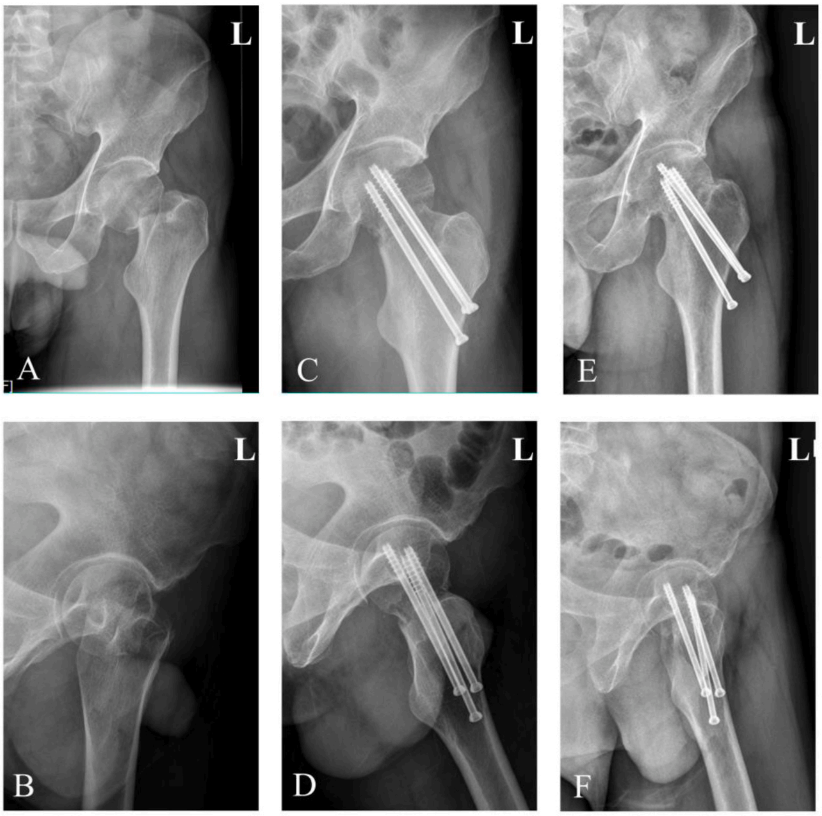

Fig. 2. A 55-year-old man with a left femoral neck fracture treated with 3CS fixation. (A, B) Preoperative radiographs illustrating the fracture of Garden type VI; (C, D) postoperative radiographs; (E, F) radiographs taken 6 months after surgery, depicting successful fracture healing along with screw extraction and significant shortening of the femoral neck.

2.5. Compound compression system

The fracture end was initially stabilized using two to three 2.5 mm Kirschner needles. Subsequently, a 5 cm incision was made on the lateral side of the upper femur, exposing the lateral wall of the greater trochanter. Employing the CCS guide, the lag screw guide needle was accurately inserted into the femoral neck, guided to a depth of 0.5 cm below the cartilage surface of the femoral head. Fluoroscopy confirmed the optimal positioning of the guide pin. In AP radiographs, the guide pin should appear in the middle to lower third of the femoral neck, whereas in lateral radiographs, it should be centrally located within the femoral neck. Following this verification, the lag screw was threaded through the guide pin, and a steel plate was positioned along the lateral femur. Successive insertion of the anti-rotating and locking screws was performed in accordance with the provided guide (Fig. 4).

2.6. Perioperative management

Cefazolin sodium was administered for infection prevention, administered 0.5 h before surgery and continued within 24 h post-operation. After ruling out anticoagulation contraindications, low molecular weight heparin was utilized for thrombosis prevention both pre and post-operatively. Post-surgery, patients were instructed to engage in quadriceps isometric contractions, active knee and ankle flexion and extension exercises, and parallel straight leg elevation exercises on the first day. Within 3 days of surgery, a radiographic examination was conducted to assess fracture end reduction and the position of internal fixation. Subsequent radiological examinations were scheduled at 1, 3, and 6 months post-operation to monitor fracture healing progress. Three months post-surgery, weight-bearing was gradually increased based on callus growth observed in X-rays until the fracture met both clinical and radiographic healing criteria, allowing patients to resume full weight-bearing activities.

2.7. Radiological assessment

1. According to X-ray evaluation, fracture healing is characterized by the formation of callus tissue bridging at the fracture site and disappearance of fracture line [17].

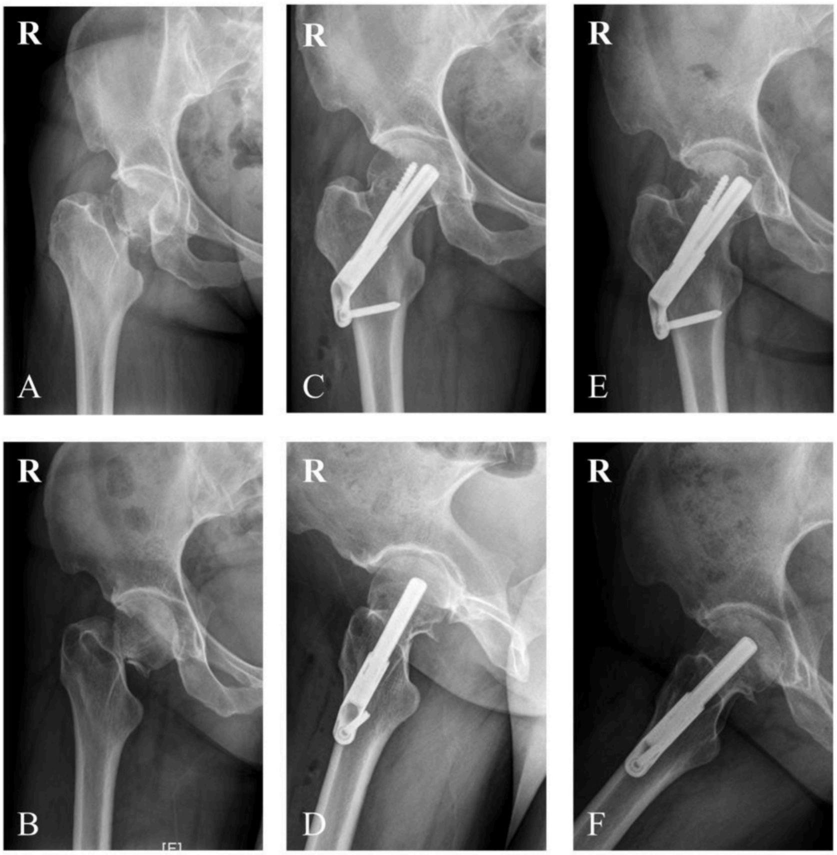

Fig. 3. A 49-year-old female with a right femoral neck fracture underwent FNS fixation. (A, B) Preoperative radiographs showed the fracture of Garden type VI; (C, D) postoperative radiographs; (E, F) 6 months after surgery, the fracture healed well with moderate shortening of the femoral neck.

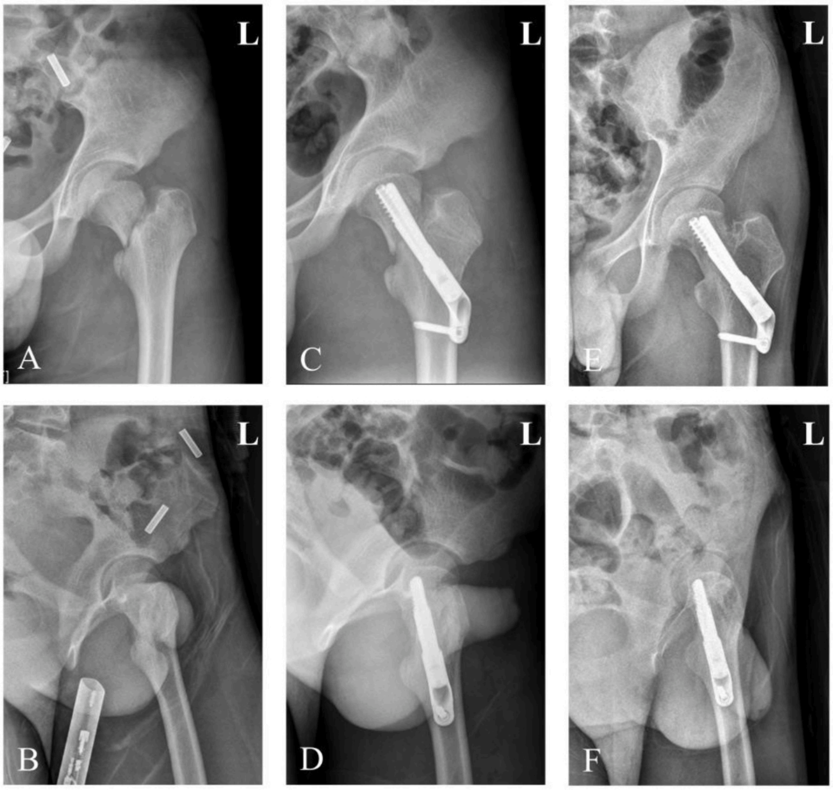

Fig. 4. A 13-year-old teenager with a left femoral neck fracture treated with CCS fixation. (A, B) Preoperative radiographs displaying the fracture of Garden type III; (C, D) postoperative radiographs; (E, F) radiographs taken 6 months after surgery, illustrating successful fracture healing.

2. Femoral neck fracture nonunion was defined as the absence of radiographic evidence of fracture union at 6 months after fracture [18].
3. Osteonecrosis of the femoral head is characterized by subchondral collapse, which can be visualized on X-ray as subchondral radiolucency, commonly referred to as the "crescent sign" [19].
4. The degree of femoral neck shortening was assessed using Zlowodzki et al.'s method. Mild shortening was defined as a distance less than 5 mm; moderate shortening was defined between 5 mm and 10 mm; severe shortening was considered when the distance exceeded 10 mm [20].

2.8. Observation target

Patients were systematically evaluated based on fracture classification, time from injury to surgery, duration of surgery, intra-operative blood loss, and the number of fluoroscopies performed. Routine clinical and imaging assessments were conducted to ascertain both the healing time and potential complications associated with the fracture. Hip function at the last follow-up was appraised utilizing the Harris score.

2.9. Statistical analysis

All data were subjected to statistical analysis using SPSS 23.0 software. Quantitative data were presented as mean ± standard deviation (SD). The independent-sample T-test was employed for comparing differences between groups when the data adhered to a normal distribution. For quantitative data not meeting the normal distribution, the rank sum test was utilized. Count data were expressed as the number of cases or percentages, and comparisons between categorical data in different groups were conducted using the chi-square test. A significance level of $P < 0.05$ was considered statistically significant, while $P < 0.01$ was considered highly significant.

3. Results

All patients were monitored for a minimum of 6 months. No significant differences were observed in age, gender, injury side, fracture type, or injury-to-operation time among the three groups ($P > 0.05$) (Table 1). Results indicated that the mean operation time in the 3CS group (109.75 ± 38.79 min) was significantly longer compared to the FNS group (83.50 ± 8.51 min) and CCS group (85.00 ± 10.41 min) ($P < 0.05$). The mean number of fluoroscopy instances in the 3CS group (25.44 ± 5.87) was also significantly higher than that in the FNS group (12.33 ± 2.64) and CCS group (13.14 ± 3.89) ($P < 0.01$). However, intraoperative blood loss in the 3CS fixation group (7.50 ± 2.58 ml) was significantly lower than that in the FNS group (100.00 ± 67.42 ml) and CCS group (114.29 ± 47.56 ml) ($P < 0.01$). During follow-up, in the 3CS group, 1 patient (6 %) experienced fracture nonunion, 4 patients (25 %) experienced femoral head necrosis, and 6 patients (37.5 %) experienced severe femoral neck shortening. In patients treated with FNS and CCS, there was no fracture nonunion, and the incidence of femoral head necrosis was 8.3 % in the FNS group and 14.2 % in the CCS group. Moreover, the FNS and CCS groups exhibited a lower incidence of severe femoral neck shortening (FNS 8.3 %, CCS 14.2 %). After excluding patients with fracture nonunion, there was no significant difference in mean fracture healing time among the three groups ($P > 0.05$). At the last follow-up, patients in both the FNS group (86.58 ± 6.47) and the CCS group (85.71 ± 5.47) showed higher Harris scores ($P < 0.05$) (Table 2).

4. Discussion

The 3CS fixation technique, widely embraced for treating femoral neck fractures in young patients, facilitates fracture healing by applying pressure to the fracture end through cannulated compression screws. These screws occupy a relatively small space in the femoral neck and head, reducing damage to the blood supply and the biological environment of fracture healing. However, the lack of correlation between the three cannulated compression screws and their limited resistance to vertical shear and torsional stress can contribute to issues such as fracture displacement, nonunion, femoral neck shortening, and femoral head necrosis [11].

DHS serves as an extramedullary angular stabilization device, offering dynamic and static compression functions. By converting shear forces into compressive stress through the sliding lag screw and dynamic compression from the lateral steel plate, it helps maintain close contact with the fracture end, promoting healing [21]. In cases of vertically displaced femoral neck fractures, DHS is effective in resisting shear stress, reducing the risk of complications like internal fixation failure, varus deformity, femoral head nonunion, and avascular necrosis [22]. Compared to the 3CS fixation technique, DHS demonstrates superior resistance to shear stress and a higher success rate in stabilizing vertically unstable femoral neck fractures. Nevertheless, DHS is characterized by a lack of rotational stability, making it susceptible to iatrogenic rotational displacement during the insertion of femoral neck screws. Consequently, the typical approach involves the addition of an anti-spinning screw to enhance rotational stability, introducing the trade-off of increased trauma and perioperative blood loss [23,24]. Moreover, the challenges are amplified in Asian populations due to the smaller cross-section of the femoral neck, making it difficult to accommodate both DHS screws and anti-rotation screws, resulting in a complex surgical procedure. The substantial size of the DHS lateral plate further complicates matters by posing difficulties in fitting the lateral femur cortex, potentially irritating the soft tissues.

In recent years, the FNS, combining the stability of DHS and the minimally invasive characteristics of 3CS, has emerged for femoral neck fracture treatment. FNS is known for its simplicity, low trauma, and improved stability through the integration of a bolt and an anti-rotation screw, mitigating the "Z" effect and enhancing overall stability and anti-rotation capability [25]. Studies have demonstrated that FNS achieves stiffness comparable to the DHS system without introducing iatrogenic rotational force, making it an effective alternative for high-shear angle femoral neck fractures [26]. Comparative studies have also shown that FNS enhances functional recovery, reduces postoperative femoral neck shortening, and minimizes intraoperative fluoroscopic exposure compared to inverted cannulated compression screws [27]. Biomechanically, FNS was found to exhibit excellent properties and superior overall structural stability when compared to 3CS fixation [28].

The Compound Compression System, similar to FNS, consists of a short side plate, a locking screw, a lag screw, and an anti-rotating screw. In the present study, both FNS and CCS demonstrated comparable clinical outcomes to 3CS fixation. There were no significant differences in surgery duration, intraoperative fluoroscopy instances, intraoperative blood loss, fracture healing time, complications, or functional outcomes. The 3CS fixation method, requiring parallel placement of three screws in an inverted triangle, necessitates repeated adjustments of the guide needles during surgery, leading to prolonged operation times and increased radiation exposure.

Table 1
Baseline characteristics.

Characteristic	3CS	FNS	CCS	P value
Cases	16	12	7	
Age (year)	47.31 ± 12.90	44.75 ± 12.38	41.43 ± 13.79	0.348
Sex				0.896
M	8	7	4	
F	8	5	3	
Side				0.849
L	10	7	5	
R	6	5	2	
Garden classification				0.966
Type I	3	2	2	
Type II	7	5	3	
Type III	4	4	2	
Type VI	2	1	0	
Injury to operation time (day)	2.34 ± 1.08	2.83 ± 0.58	2.86 ± 0.69	0.169

Table 2
Comparison of perioperative conditions and clinical outcomes in different groups.

Characteristic	3CS	FNS	CCS	χ2	P value
Operation time (min)	109.75 ± 38.79	83.50 ± 8.51	85.00 ± 10.41	7.55	0.023
Number of Fluoroscopy	25.44 ± 5.87	12.33 ± 2.64	13.14 ± 3.89	24.34	0.000
Blood loss (mL)	7.50 ± 2.58	100.00 ± 67.42	114.29 ± 47.56	27.20	0.000
Fracture healing (months)	4.20 ± 1.37	3.92 ± 1.00	3.86 ± 0.90	1.385	0.892
Femoral neck shortening					
<5 mm	6 (37.5 %)	7 (58.3 %)	3 (42.9 %)		
5–10 mm	4 (25 %)	4 (33.3 %)	3 (42.9 %)		
>10 mm	6 (37.5 %)	1 (8.3 %)	1 (14.2 %)		
Nonunion	1 (6 %)	0	0		
Femoral head necrosis	4 (25 %)	1(8.3 %)	1(14.2 %)		
Harris hip score	80.88 ± 7.49	86.58 ± 6.47	85.71 ± 5.47	6.795	0.033

However, 3CS fixation, without the need for incisions and steel plate placement, resulted in lower intraoperative blood loss, aligning with the minimally invasive concept. During the follow-up period, patients treated with either FNS or CCS fixation exhibited a reduced incidence of severe femoral neck shortening and femoral head necrosis. Moreover, the average hip function scores in both FNS and CCS groups surpassed those observed in the 3CS fixation group. This improvement can be attributed to the "nail in nail" design of both FNS and CCS, which provides excellent anti-rotation and angular stability, effectively preventing loss of reduction. Additionally, both fixation systems offer a designated space for sliding compression. FNS allows for a compression space of 20 mm, while CCS provides a sliding distance of 15 mm. Throughout the healing process of femoral neck fractures, dynamic compression of the fracture end occurs due to the absorption of the fracture fragments, thereby facilitating fracture healing.

Previous studies have consistently highlighted the potential negative consequences of femoral neck shortening, emphasizing its association with weakened abductor torque on the greater trochanter, resulting in limb weakness, pain, and reduced patient satisfaction. A multicenter study by Slobogean et al. in China found that femoral neck shortening of ≥10 mm was linked to poorer hip function outcomes in adult femoral neck fracture patients under 55 years old [29]. Another study by Zlowodzki et al. on 56 patients with femoral neck fracture observed that the use of multiple cancellous bone screws on the fractured end of the femoral neck could lead to shortening and negatively impact body function [30]. Consistent with these findings, our study demonstrated an association between femoral neck shortening and poorer hip function.

It is crucial to highlight that the CCS involves the addition of an anti-rotating screw to the lag screw of the DHS, aiming to improve the angular stability of internal fixation. Similar to the DHS, the CCS exhibits a large lag screw diameter, which poses a risk of iatrogenic rotation of the proximal fracture [31]. Fig. 3 illustrates a satisfactory initial fracture reduction during the operation, yet the excessive torsion force upon lag screw insertion led to rotational displacement of the fracture fragment on the femoral head side. Although the outcome was favorable, the long-term follow-up remains unclear. Min et al. showed that poor reduction is an important risk factor for avascular necrosis of the femoral head [32]. In a retrospective study by Fang Pei et al. involving 250 patients with an average follow-up of 7.5 years, it was found that postoperative femoral head necrosis occurred in 9.7 % (16/165) of cases with satisfactory reduction and 28.2 % (24/85) with poor reduction [6]. Notably, poor reduction quality significantly increased the risk of necrosis. Inadequate reduction of the fracture end exerts a continuous stretch force on residual blood vessels, impairing vascular reconstruction and leading to blood supply disorders, potentially resulting in fracture nonunion and femoral head necrosis [33,34]. In addition, poor reduction contributes to an ill-matched femoral head and acetabulum, resulting in the trabecular bone at the femoral head being subjected to both axial and shear stress, can also lead to femoral head necrosis [35]. Therefore, we advocate the insertion of two to three 2.5 mm Kirschner wires from the upper edge of the femoral neck along the axial direction before CCS lag screw insertion to resist iatrogenic rotational stress. Although several design differences exist between CCS and FNS, such as lag screw diameter, anti-rotating screw diameter, cross-angle between anti-rotating screw and lag screw, post-operative sliding compression distance, locking screw fixation angle, etc., our study did not identify any impact of these differences on the clinical outcomes of femoral neck fractures.

Nonetheless, our study has limitations, including the absence of biomechanical tests to analyze fixation stability differences among the three systems, an insufficient case number, and the need for validation through a larger clinical dataset. The short follow-up duration (<2 years) precluded a determination of the long-term incidence of postoperative femoral head necrosis. Blood loss and operation duration are critical metrics for assessing surgical safety. A study by Cao MM et al. indicated that patients who received regional anesthesia experienced reduced operation times, shorter hospital stays, and decreased intraoperative blood loss compared to those given general anesthesia [36]. However, as the anesthesia method was not a variable in this study, there might be discrepancies in the assessment of intraoperative blood loss and operation duration across the three surgical techniques examined. Future studies should address these limitations, and we anticipate further refinements in subsequent research.

5. Conclusions

Both FNS and CCS are effective for treating femoral neck fractures in young patients, outperforming 3CS in achieving satisfactory clinical functional outcomes. Comparatively, the CCS system presents a higher risk of iatrogenic rotation of the proximal fracture segment. Therefore, we advocate the insertion of two to three 2.5 mm Kirschner wires from the upper edge of the femoral neck along the axial direction before CCS lag screw insertion to resist iatrogenic rotational stress.

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Ethical statement

This study by Ningde Traditional Chinese Medicine Hospital ethics committee approval (2023006).

Informed consent statement

Informed consent was obtained from all subjects involved in the study.

Data availability statement

Data were not stored in publicly available repositories due to privacy and permission issues. The authors will supply the relevant data in response to reasonable requests.

CRediT authorship contribution statement

Xinzhao Zhang: Writing – original draft, Data curation. **Changling Zheng:** Data curation. **Jin Huang:** Data curation. **Hui Chen:** Data curation. **Jie Lei:** Data curation. **Cong Huang:** Writing – review & editing, Supervision, Data curation, Conceptualization.

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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