CLINICAL ARTICLE

A Comparative Analysis of Femoral Neck System and Three Cannulated Screws Fixation in the Treatment of Femoral Neck Fractures: A Six-Month Follow-Up

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Objective: To investigate the efficacies of Femoral Neck System (FNS) and the three cannulated screws fixation (3CS) as therapeutic options for femoral neck fractures.

Method: This was a retrospective study involving 69 patients (26 males and 43 females; mean age of 54.9 years (range, 28–66 years)) subjected to either FNS or 3CS for femoral neck fracture therapy. These patients were treated in our hospital from October 2019 to May 2020. Patient follow up was done at 1, 2, 3 and 6 months. During the short-term (6 months) follow-up period, surgical procedures for the two groups and incidences of complications were analyzed. Perioperative parameters were recorded and analyzed. Postoperative hip joint functions were measured and compared using the Harris score. The assessed perioperative parameters included surgical time, hemoglobin loss, fluoroscopy duration, hospitalization length and hospitalization cost. The main complications at last follow-up (6 months) included varus tilting, femoral neck shortness, and implant removal.

Results: Differences in the number of patients, age, Garden type of fracture and time from injury to surgery between the two groups were not significant ($P > 0.05$). With regards to perioperative parameters, compared to 3CS, FNS treatment performed better in surgical time (60.00 ± 12.44 *vs* 76.81 ± 13.10 min, $P = 0.000$), blood loss (13.67 ± 8.02 *vs* 16.58 ± 4.16 g/L, $P = 0.059$) and fluoroscopy time (39.73 ± 9.57 *vs* 58.14 ± 9.15 s, $P = 0.000$). Differences in hospitalization length and cost between the groups were not significant ($P > 0.05$). During the whole follow-up period, all patients did not exhibit dysfunction, pulmonary embolism or even death as a result of long-term immobilization of affected limbs. Surgical incisions for all patients healed well without infections. During the 6-month follow-up period, the FNS group exhibited a higher Harris score (84.61 ± 3.42 *vs* 78.67 ± 3.72, $p = 0.000$). In addition, treatment-associated complications (FNS *vs* 3CS) included femoral neck varus tilt (3.03% *vs* 11.11%), femoral neck shortness (6.06% *vs* 13.89%), and implant removal (0% *vs*. 13.89%). Implant removal rate for the FNS group was significantly less than that of the 3CS group ($P = 0.026$). Differences in incidences of femoral neck varus tilt ($P = 0.196$) and femoral neck shortness ($P = 0.282$) between the two groups were not significant. However, the difference in number was significant (FNS group was less).

Conclusion: FNS treatment is associated with a smaller surgical trauma, stronger stability, and reductions in post-operative complication incidences, therefore, it is a potential therapeutic option for femoral neck fractures.

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Introduction

Hip fractures are common in falls and traffic accidents. Due to long-term bed rest after surgery, these types of fractures are associated with a high morbidity and mortality rates. Femoral neck fractures account for about half of hip fractures. For the AO31-B type fractures, there is substantial shear stress and rotational instability at fracture fragments. It is challenging to obtain complete stability in surgical internal fixation, which may easily lead to complications such as varus tilting, implant removal, fracture displacement, non-union and femoral head necrosis. In young patients, femoral neck fractures are attributed to high-energy violence[1]. For relatively young patients with femoral neck fractures, efficient surgical therapeutic options have not been established[2,3]. Complications and high revision rates exert high physical and mental burden to patients, increases medical care costs as well as social and economic pressure[4]. In the treatment plan to repair the femoral neck, long-term preservation of hip joint functions is more important than the surgical process. However, the surgical process affects the long-term therapeutic outcomes of different implants on femoral neck fractures. Therefore, it is important to comprehensively compare the advantages associated with different implants[5]. Currently, for young patients with femoral neck fractures, surgical therapeutic options are preferred.[2] For older patients (more than 65 years old) with femoral neck fractures, osteoporosis affects the stability of implants. Long-term bed rest after surgery is associated with various complications and reduces the survival rate for patients. In addition, unstable bone healing rates among elderly patients reduces surgical success rates. However, for cases with difficult reductions and poor prognostic outcomes, hemi-joint replacement should be an option[6,7]. The new type of femoral neck osteosynthesis is associated with convenient surgical procedures, less trauma, and stronger fixation[8]. It is designed to effectively preserve the femoral neck and enhance healing.

Currently, 3CS, dynamic hip (DHS), DHS combined with anti-rotation screws and many different surgical techniques aimed at retaining the femoral neck are used to treat femoral neck fractures[9,10]. However, the non-union rate after femoral neck fracture surgery is 33%, while the rate of revision surgery is as high as 18%[11]. This high failure rate is attributed to the inability to maintain sufficient biomechanical stabilities during postoperative fracture healing[12]. 3CS is fixed with three parallel hollow screws, which has the effect of dynamic sliding compression. Under certain conditions, it achieves close contact of fracture fragments, thereby facilitating fracture healing. In addition, compared to the other fixation methods, 3CS procedures are less invasive with less blood loss, and shorter hospital stay time. However, for femoral neck fractures with shear force at the fracture end and unstable rotation, various complications occur when ordinary hollow screws are used for fixation, including displacement, screw loosening, femoral neck shortening, varus deformity, and non-union. Therefore, different surgical options must be evaluated to ensure the best treatment options for young patients with femoral neck fractures.

The Femoral Neck System (Femoral Neck System, Zuchwil, Switzerland) is a surgical option for femoral neck fracture therapy. Its advantages include anti-rotation, angular stability, dynamic fixation and minimally invasive surgical procedures[13]. This system has a 10 mm bolt, an anti-rotation screw, an outer plate and a locking nail. A biomechanical study on FNS confirmed that FNS exhibits significant advantages in resisting varus deformation, femoral head dorsal tilting and femoral head rotation[12]. In addition, this study revealed that FNS and DHS have comparable outcomes with regards to fracture fixation and complications. However, clinical efficacies of DHS and FNS have not been established. In terms of fixation mechanisms, DHS is similar to FNS.

This study collected and analyzed the clinical data for patients undergoing FNS and 3CS surgical procedures for femoral neck fracture treatments. We aimed at: (i) evaluating the therapeutic effects of femoral neck internal fixation surgery (FNS) for young patients with femoral neck fractures; (ii) analyzing and comparing surgical procedures and clinical effects of FNS and 3CS in femoral neck fracture treatment, (iii) elucidating on the surgical procedures and operation skills of FNS, and (iv), comparing and analyzing the internal fixation stability of FNS and 3CS as well as the incidence rate of complications.

Methods

Patients

We retrospectively analyzed data from 69 patients (≤65 years) with femoral neck fractures who had been admitted to our institution from October, 2019 to May, 2020. The type of fracture was AO31-B (Garden Types II, III, and IV). Thirty three patients were subjected to FNS treatment, and 36 were subjected to 3CS treatment. The fractures were highly correlated with traffic accidents or falls. The inclusion criteria were: (i) patients younger than 65 years with fresh femoral neck fractures; (ii) fractures were AO31-B type; (iii) patients treated with FNS or 3CS; (iv) patients who completed at least half a year of follow-up; (v) patients with postoperative radiological and joint function measurement data and (vi) retrospective studies. The exclusion criteria were: (i) hip dysfunction before injury; and

(ii) presence of other fractures or other diseases that affect femoral neck treatment (pathological fractures and rheumatoid diseases among others).

All patients were voluntarily subjected to FNS or 3CS treatment. FNS was obtained from DePuy Synthes (Zuchwil, Switzerland). Ethical approval for this study was obtained,

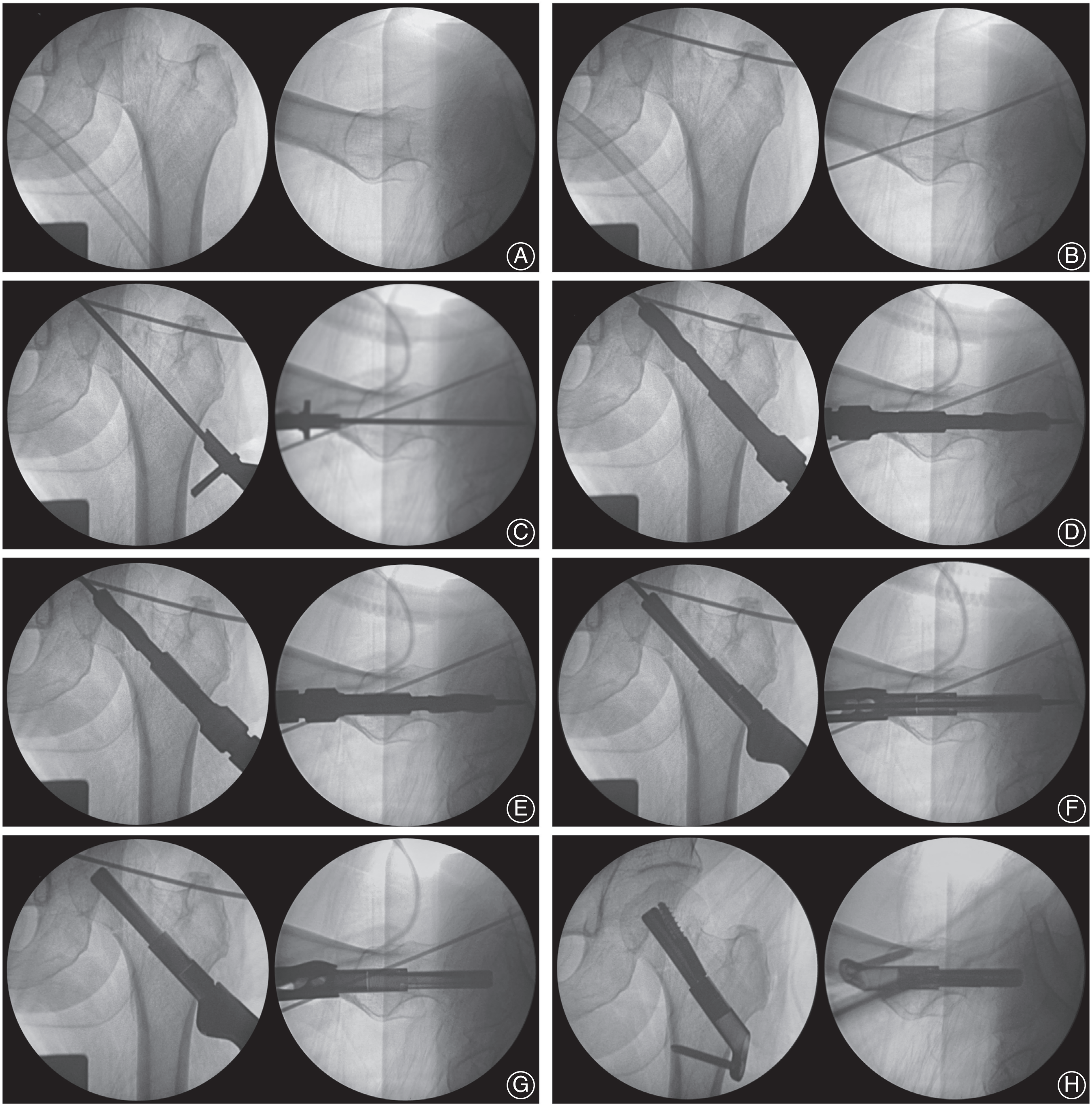

Fig. 1 (A) Manipulative reduction of the femoral neck before surgery, preoperative frontal and axial X-rays of the hip joint showed that the femoral neck was well aligned; (B) The anti-rotation guide needle was inserted, with the position of the guide needle avoiding the center of the femoral neck to leave space for the bolt; (C) The bolt guide pin was inserted and localized at the center of the femoral neck in the positive and lateral X-ray of the hip joint; (D and E) Reamed along the guide pin (center distance ≤10 mm); (F) Knocked and inserted the bolt and outer steel plate along the guide needle; (G) The guide needle was pulled out; (H) The anti-rotation screw and locking nail were inserted, and the fixed guide needle pulled out

and all patients signed written informed consent prior to their inclusion in this study.

Preoperative Preparation

After admission, patients were subjected to preoperative routine examinations, including laboratory analysis and imaging of the affected hip. Imaging included frontal and axial X-rays of the hip joint, computed tomography (CT) and three-dimensional reconstruction. Before performing the surgical techniques, analgesics were administered based on patients symptoms. Moreover, prevention and treatment of deep vein thrombosis of lower extremities were performed before commencing surgical procedures while anticoagulant administration was stopped at 24h before surgery. Surgical approaches were determined by two attending physicians.

Surgical Methods

Both patient groups were subjected to epidural anesthesia or general anesthesia. Under the G-arm machine perspective, the traction bed was used to reduce the fracture. FNS: The anti-rotation guide pin was fixed in the femoral neck while insertion of the anti-rotation guide needle in the center of the femoral neck was avoided. A longitudinal incision was made on the lateral side of the femur to reach the lateral femoral cortex (about 3–4 cm). The bolt guide needle was located in the center of the femoral neck, then, the reaming drill was used to guide the needle along the bolt to ream the medulla. With the aid of a connecting rod, the bolt was gently tapped into the femoral neck medullary cavity and the outer steel plate placed on the outside. After satisfactorily fitting the bolt and plate, 1–2 locking screws (5 mm) and the anti-rotation screw were inserted (Fig. 1). 3CS: three screws were placed in a parallel symmetry, forming an isosceles-inverted triangle.

Postoperative Management

This included antibiotic administration within 3–5 days after surgery as well as anticoagulant and lower extremity pneumatic pump therapy to prevent venous thrombosis of the lower extremities. On the second day after surgery, on bed functional rehabilitation exercises were performed, weight-bearing activities within 1 month after surgery were inhibited and rehabilitation guidance was performed based on follow-up outcomes. At about 3 months after surgery, based on bone healing, weight-bearing walking was allowed.

Follow Up and Hip Research Indices

Surgical time, hemoglobin loss, fluoroscopy duration, hospitalization length, hospitalization cost and Harris scores for the two groups were recorded. Hemoglobin loss was expressed as preoperative hemoglobin value minus the hemoglobin value of the second day after surgery. Postoperative complications included femoral neck varus tilting, femoral neck shortness, and implant removal. Harris scores of the two patient groups were evaluated at 6 months after surgery[14].

The Harris score (HHS) system assesses four aspects: pain, function, absence of deformity and range of motion. The score standard had a maximum of 100 points. Total scores <70 points were considered poor scores, 70–80 points were fair, 80–90 points were good while 90–100 points were excellent scores.

TABLE 1 Demographic distribution of patients

Demographics	FNS, $n = 33$	3CS, $n = 36$	t/χ^2	P
Age (years, mean ± SD)	57.61 ± 11.87	52.50 ± 10.72	1.878	0.065
Gender (n, %)			0.509	0.475
Female	11 (33.33%)	15 (41.67%)		
Male	22 (66.67%)	21 (58.33%)		
Garden type (n, %)			0.160	0.689
Type II	10(30.30%)	12(33.33%)		
Type III	9 (27.27%)	14 (38.89%)		
Type IV	14 (42.42%)	10 (27.78%)		
Time from injury to surgery (day, mean ± SD)	1.79 ± 0.86	1.56 ± 0.73	1.212	0.230

TABLE 2 Comparisons of surgical outcomes in the two groups (mean ± SD)

Surgical outcomes	FNS, $n = 33$	3CS, $n = 36$	t	P
Surgical time (min)	60.00 ± 12.44	76.81 ± 13.10	−5.453	0.000
Hemoglobin loss (g/L)	13.67 ± 8.02	16.58 ± 4.16	−1.918	0.059
Duration of fluoroscopy (seconds)	39.73 ± 9.57	58.14 ± 9.15	−8.168	0.000
Hospitalization length (days)	7.57 ± 2.39	8.50 ± 1.95	−1.763	0.082
Hospitalization cost (dollars)	6001.22 ± 649.49	5694.03 ± 682.26	1.912	0.060
Harris score	84.61 ± 3.42	78.67 ± 3.72	6.887	0.000

Statistical Analysis

The SPSS version 23.0 (SPSS Inc. Chicago, IL, USA) was used for statistical analyses. Femoral neck varus tilting, femoral neck shortness rate, and implant removal rate are expressed as percentages (%), and analyzed by the chi-square test. Surgical time, hemoglobin loss, duration of fluoroscopy, hospitalization length, hospitalization cost and Harris scores are expressed as mean ± standard deviation, and were analyzed by the independent-samples *t*-test. $P \leq 0.05$ was considered statistically significant.

Results

Demographic Data

The last follow-up time for the two groups was set at 6 months. Differences in demographic data, including age, gender, Garden Types as well as in time from injury to surgery between the two groups were not significant ($P > 0.05$). The dates are listed in Table 1.

Surgical Outcomes

At first, surgical incisions for the two groups healed without infections. Differences in the amount of surgical bleeding (the difference in hemoglobin), length of hospital stay, and hospital expenses between the two groups were not significant. Surgical time and intraoperative fluoroscopy duration for FNA was significantly shorter than that of 3CS ($P < 0.05$). Harris scores were obtained by assessing the degree of pain, daily activities and range of motion. After the 6-month follow-up period, the Harris score for FNS was significantly better than that of 3CS (Table 2).

Complications

During follow-up, mortalities or pulmonary embolism were not recorded in any of the two groups. The main complications included femoral neck inversion, shortening of femoral neck, and implant withdrawal. Differences in incidences of femoral neck varus and femoral neck shortening between the

TABLE 3 Comparisons of postoperative complications

Complications	FNS, $n = 33$	3CS, $n = 36$	χ^2	P
Varus tilting (n, %)	1 (3.03%)	4 (11.11%)	1.673	0.196
Femoral neck shortness (n, %)	2 (6.06%)	5 (13.89%)	1.157	0.282
Implant removal (n, %)	0	5 (13.89%)	4.941	0.026

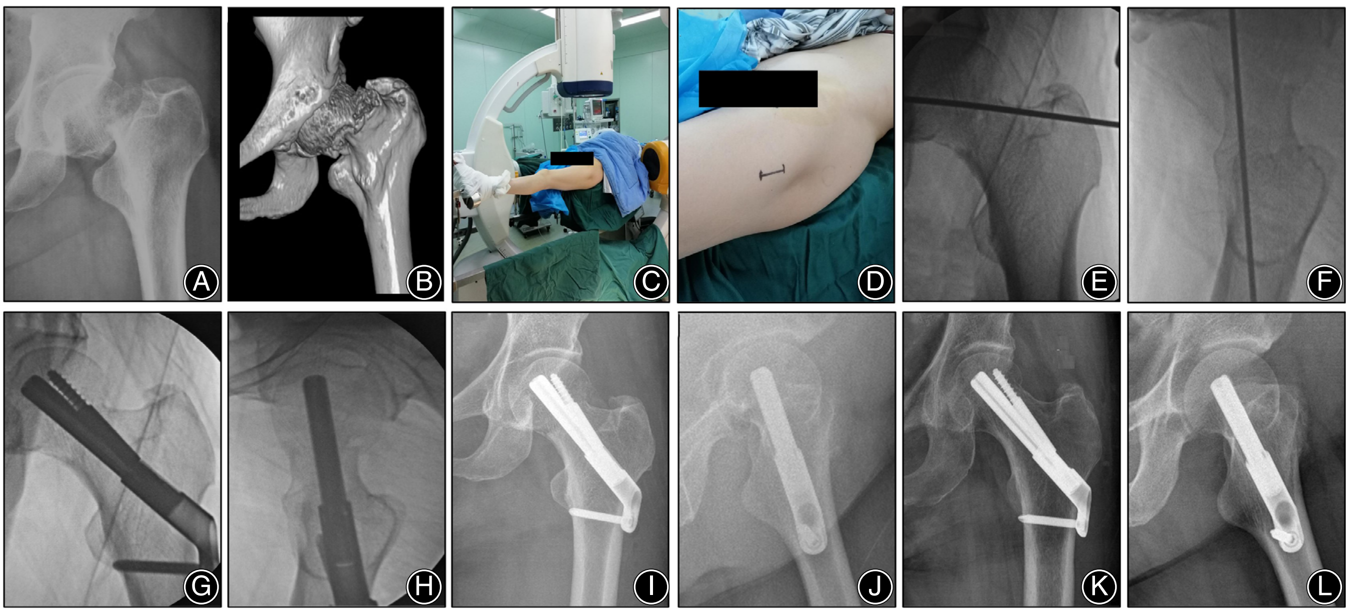

Fig. 2 A 49-year-old female patient with left femoral neck fracture was treated with FNS. (A and B) Preoperative X-ray and CT three-dimensional reconstruction examination showed a left Garden type IV femoral neck fracture; (C and D) G-arm machine fluoroscopy, manual traction and reduction of femoral neck fractures, exposing the lateral side of femur and femur for surgical marking; (E and F) A fixed guide pin was inserted to fix the femoral neck in order to prevent it from rotating and shifting during the operation; (G and H) Postoperative hip joint frontal and axial X-rays revealed that the femoral neck was reduced and that the internal fixation position was good; (I and J) At 1 month of post-operative follow-up, hip joint frontal and axial X-rays showed a good internal fixation position and callus existence; (K and L) At 6 months of post-operative follow-up, frontal and axial X-rays of the hip joint showed that the fracture had healed and that the internal fixation position was good

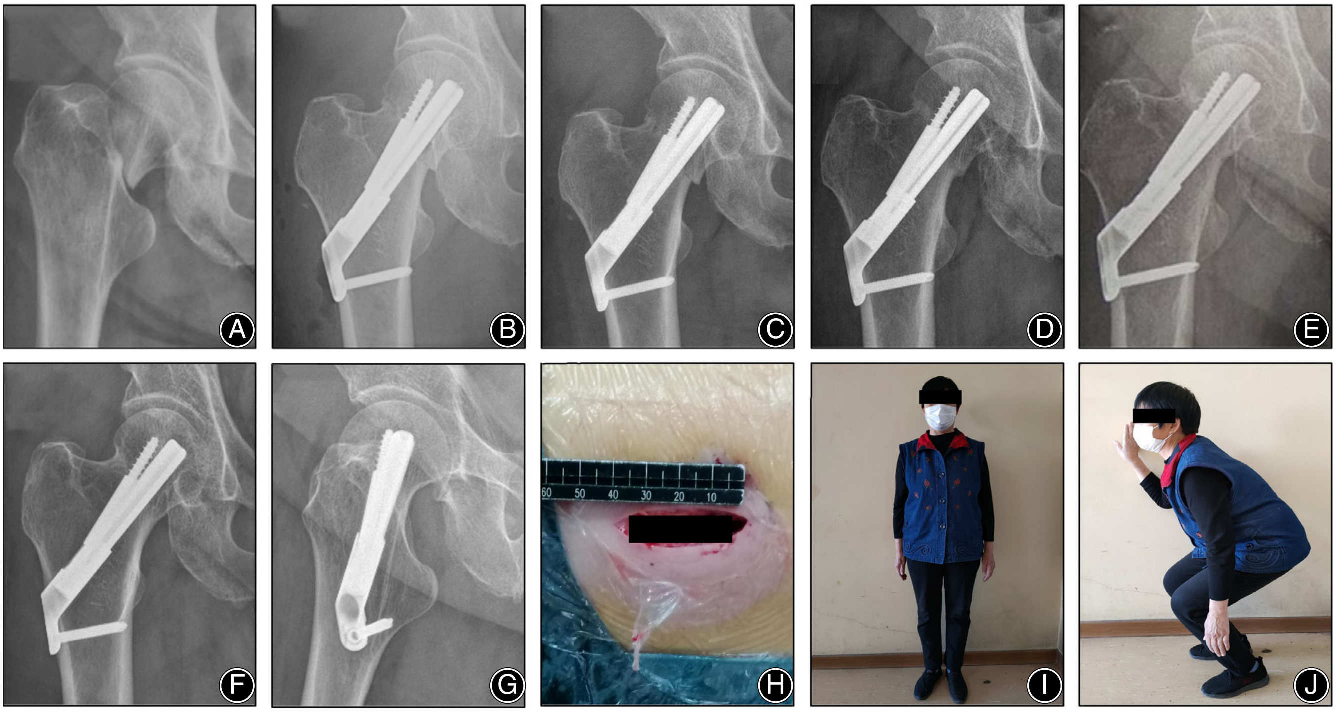

Fig. 3 A 52-year-old female patient with left femoral neck fracture was treated with FNS. (A) Before surgery, frontal X-ray imaging showed Garden IV femoral neck fracture; (B) Postoperative hip joint X-ray imaging showed that internal fixation position of the fracture was good; (C, D and E) At 1, 2 and 3 months, post-operative hip joint X-rays showed good femoral neck fracture healing; (F and G) At 6 months, post-operative hip joint frontal and axial X-rays showed that the fracture had healed; (H) Surgical incision length was about 4–5 centimeters; (I and J) At 6 months after fracture healing, the patient was able to walk normally without squatting obstacles

two groups were not significant. However, FNS was less in number than 3CS. Implant withdrawal rate for 3CS was significantly higher than that of FNS ($P = 0.026$; Table 3).

Typical cases are shown in Figs 2 and 3.

Discussion

Fixation and Surgical Procedures of FNS

The FNS design involves minimally invasive surgical procedures for internal stability. Due to the special anatomical structure and blood supply characteristics of the femoral neck, a strong internal implant fixation is required to provide conditions for fracture healing, and to protect the fragile blood supply of the femoral neck[15]. Even young patients with femoral necks face a high risk of failure[16]. Surgical fixation success depends on many factors, such as the type of fracture, preoperative reduction, internal fixation stability, soft tissue damage (preservation of blood supply to the femoral head) and patient's medical compliance[17–20]. The selection of suitable internals is very important for surgeons and patients.

A biomechanical study performed on cadaver specimens revealed that FNS-associated structural stability is better than that of 3CS[13]. However, differences between the two in actual clinical settings have not been elucidated. Compared to 3CS, we found that 6 months after surgery, FNS exhibits better outcomes with regards to surgical time, fluoroscopy time and Harris score. In our surgical procedures, first, we fixed the femoral head on the acetabulum or femoral neck with a guide pin to prevent displacement of the fractured end during surgery. Guide pin positioning should avoid the femoral neck center so as not to affect bolt positioning. Initial insertion of femoral neck bolt guide needle does not need to be very accurate. A reasonable use of the "locator" can effectively shorten guide needle positioning time and achieve effective positioning. The use of the positioner also shortens the surgical time. To achieve stability, the three screws of 3CS should be accurately positioned, which greatly increases the number of fluoroscopy and surgical time duration. A shorter surgical time reduces the risk of intraoperative surgery, and the risk of damage attributed to anesthesia, which represents less trauma[21]. The amount of surgical blood loss in the FNS group (13.67 ± 8.02) was less than that in the 3CS group (16.58 ± 4.16), however, the difference was not significant ($P = 0.059$). Not only is the amount of bleeding reflected in surgical time, partial incision of the lateral bone muscle is a relatively small incision, which reduces postoperative soft tissue pain. The outer steel plate can select single hole or double hole. The smaller outer titanium plate effectively reduces surgical incision depth and the coverage area of the implant, which protects blood supply of the outer cortex.

Anti-Rotation and Angular Stability of FNS

FNS stability is attributed to anti-rotation and angular stability. The anti-rotation screw is attached to the bolt, which reduces blood supply defects to the femoral neck by the screw. At the same time, it provides a large surgical space for patients with narrow femoral necks. The degree of fit between the lateral plate and the lateral femoral cortex should be seriously considered. Placement angle of the bolt should be controlled at 130°–135° to prevent the outer side of the steel plate from irritating the soft tissue, thereby, causing pain in the outer soft tissue. Percussion and placement of the bolt exerts some pressure on the surrounding bone, which preserves the bone mass and avoids the risk of femoral head rotation caused by nail rotation. The bolt angle should be considered during the percussion process, and the fixing functions of the positioning guide pin as well as the bolt guide pin are particularly important[19]. Although studies have not evaluated the importance of tip-caput distance ≤10 mm, we still used tip-caput distance ≤10 mm as the surgical standard for our procedures.

In this study, the difference in time from hospital admission to surgery between the two groups was not significant. Hoelsbrekken *et al.* documented that surgical delays can affect fracture healing[22]. In this study, the difference in hospitalization costs between the two groups was not significant, however, that of the 3CS group was lower than that of the FNS group, which was attributed to the price of the implant. Treatment costs cannot be solely measured by hospitalization expenses, they must also be combined with patient's own treatment experience, long-term follow-up effects, as well as whether joint replacement is required[23]. Since 3CS is not a holistic structure like FNS, screw position is easily affected by the surgeon's subjective factors. In addition, compared to 3CS, due to its locking mechanism, FNS has no nail withdrawal.

Postoperative Complications of FNS

During the 6-month follow-up period, the rate of avascular necrosis (AVN) and non-union in the study was not recorded, we focused on incidences of internal fixation failure. AVN is a serious postoperative complication[24,25]. Parker *et al.* reported that AVN rate for undisplaced femoral neck fractures was 4.5%, while AVN rate for displaced fractures was 11.1%. Occurrence of AVN in the short term means surgical failure, however, assessment of AVN requires two years of follow-up[26]. During the six-month follow-up, no AVN was observed in the two groups. Appropriate weight-bearing after osteosynthesis can make the proximal and distal ends of the fracture to contact, thereby, enhancing fracture site stability and healing. However, excess compression can cause the femoral neck to be significantly shortened and the screw to protrude[27]. Compared to rigid fixation, dynamic fixation and appropriate axial micro-movement are conducive for callus formation and bone cortex healing[28]. FNS has a sliding pressure space of 20 mm, which is conducive for effective contact between broken ends. In addition, after implantation of the locking screw, the plate and bolt form an angled stable structure. A biomechanical study revealed that FNS has a stronger angular stability than 3CS, with a higher resistance to femoral neck shortening and varus rotation[13]. At the same time, the occurrence of femoral neck shortening and varus is closely correlated with patient's medical compliance. The locking nail of FNS inhibits implant withdrawal. These complications are mechanical. The complication rate of displaced fractures is significantly higher than that of undisplaced fractures. In conclusion, accurate reduction and sufficient implant stability are key to reducing complications[20,29,30].

Limitations of this Study

This study has some limitations. First, displacement of the initial fracture is different, and different fracture types affect postoperative complication incidences. However, preoperative reduction cannot guarantee that all fractures reach the ideal state. Differences in fracture displacement may cause a bias in incidences of complications. Second, the follow-up time was only 6 months, which does not account for a complete treatment process. In the next study, we will expand the sample size for long-term follow-up, and assess the occurrence of fracture non-union and AVN.

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