CLINICAL ARTICLE

"In-Out-In" Percutaneous Reduction Technique for Treatment of Valgus-Impacted Femoral Neck Fractures: A Technical Trick and Case Series

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Objective: Valgus-impacted femoral neck fractures with or without posterior tilt of the femoral head are very common and full of pitfalls in clinical practice, which may lead to femoral neck shortening (FNS) and avascular necrosis (AVN). The study tries to introduce a novel technical trick aiming at anatomical reduction of valgus-impacted femoral neck fracture with minimally invasive procedure, and summarize the clinical prognosis in case series.

Methods: In this retrospective study, 24 patients (seven men and 17 women) with valgus-impacted femoral neck fractures between May 2017 and July 2020 were managed by "in-out-in" percutaneous reduction technique (percutaneous reduction group). Another 24 cases (10 men and 14 women) suffering the fractures underwent *in situ* fixation were enrolled as control group for function comparison (*in situ* fixation group). All patients were followed up for 24–42 months. The clinical outcomes included complications after operations (χ^2 test) and Harris Hip Score (HHS) for hip function (unpaired *t* test) in the two groups. The radiographic outcomes were evaluated by collodiaphyseal angle, posterior tilt angle, and FNS before the operation and during the follow-up in the percutaneous reduction group (unpaired *t* test).

Results: Patients' preoperative data, including age, sex, affected side, fracture types, and medical history, were similar between the two groups, respectively ($p > 0.05$). After surgery, the mean HHS at 6, 12, and 24 months were all better in the percutaneous reduction group (76 ± 6.72, 85.34 ± 6.33 and 90.54 ± 5.81) than that in the *in situ* fixation group (70.86 ± 6.91, 80 ± 6.11 and 84.1 ± 7.82), respectively ($p < 0.05$). One patient suffered fixation failure with screws retreat and one patient suffered AVN in the percutaneous reduction group. In the *in situ* fixation group, AVN occurred in two patients at last follow-up. There was no significant difference in complication amounts between the two groups ($p > 0.05$). In the percutaneous reduction group, collodiaphyseal angle, posterior tilt angle, and amount of FNS were significantly different between preoperative cases and immediately postoperative cases ($p < 0.05$). However, there was no statistical difference of the measurements among postoperative cases at different time points (within 24 h, 6 months, and 2 years postoperatively) ($p > 0.05$).

Conclusions: Our experience of the technique and the case series show that "in-out-in" percutaneous reduction technique for treatment of valgus-impacted femoral neck fracture with or without posterior tilt of the femoral head is safe and effective for achieving successful bone union and satisfactory function.

Key words: Femoral neck fracture; Percutaneous reduction; Posterior tilt; Valgus impaction

Introduction

Hip fractures predominantly affect elderly patients, with a reported incidence of 12% of all fractures in adults. Femoral neck fractures comprise 50% of all hip fractures,[1] of which 32%–38% are un-displaced type[2] and 15%–20% are valgus-impacted femoral neck fracture of total femoral neck fractures.[3] As the common type of the fractures, valgus-impacted femoral neck fractures are considered clinically

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stable.[4] The treatment for this fracture type preferred *in situ* fixation with parallel cannulated screws.[5,6]

Although the prognosis of valgus-impacted femoral neck fracture is better than that of displaced femoral neck fracture, previous studies reported that severe valgus impaction >15° was associated with a high rate of avascular necrosis (AVN) and femoral neck shortening (FNS).[2,7] Some studies verified that FNS could cause a significant decrease in abductor strength[8] and anterior femoroacetabular impingement, which would lead to progressive hip arthrosis.[9,10] Another study[11] compared fixation after reduction of valgus-impacted femoral neck fracture and *in situ* fixation. The result showed that the former was safe and effective for achieving successful bone union and restoring femoral neck length. And the risk of FNS >5 mm was significantly decreased, which would lead to better functional outcomes.

Furthermore, valgus-impacted femoral neck fractures were often accompanied with varying degrees of posterior tilt deformities. Patients with an initial valgus and posterior tilt >15° are in high risk of AVN and fixation failure.[2,12,13] Therefore, achieving reduction of valgus-impacted femoral neck fracture, especially with severe posterior tilt, is vital during surgical intervene.

Several closed reduction techniques for valgus-impacted femoral neck fracture have been described. Park *et al.*[11] used a Schanz pin as manual traction for reduction. During operation, a Schanz pin was inserted transversely into the middle one-third of the trochanter from the lateral aspect, and lateral manual traction was applied under fluoroscopic guidance using a universal chuck with T-handle until satisfactory reduction. Zhu *et al.*[14] fixed the femoral head to the acetabulum by two crossed Kirschner wires from anterior and lateral side of the hip. Under the monitoring of intraoperative fluoroscopy, the injured limb was gradually adducted, rotated inward, and retracted against direction of fracture displacement with traction table. Yu *et al.*[15] reported a technique of three-dimensional interactive reduction for treatment of irreducible femoral neck fracture. Two Kirschner wires were inserted into the anterior of the femoral neck for controlling rotation of the femoral head and the distal end of the fracture was performed with manual traction by surgical assistants for fracture reduction. However, the techniques may require more surgical assistants and plentiful experience. Furthermore, reduction of posterior tilt is not controllable.

In clinical practice, traction technique applied by traction table alone often fails to achieve reduction of impacted fracture and posterior tilt displacement. The closed reduction techniques mentioned above may achieve satisfactory reduction but require higher surgical skills and more assistants. Hence, we describe a percutaneous reduction technique using one Steinmann pin for anatomical restoration of the femoral neck in the surgical treatment of the valgus-impacted femoral neck fracture with or without posterior tilt. The study regards the following three points in clinical practice: (i) key points and focus of the technique during the surgery; (ii) reduction quality of the femoral neck fractures after the use of the technique; and (iii) intermediate prognosis of the fracture including functional outcomes and complications.

Methods

Inclusion and Exclusion Criteria

Inclusion criteria: (i) patients suffered valgus-impacted femoral neck fracture with or without posterior tilt; (ii) patients could tolerate surgery and consented to surgical treatment by "in-out-in" percutaneous reduction technique.

Exclusion criteria: (i) patients were older than 65 years old or suffered severe osteoporosis, which were more suitable for arthroplasty. (ii) patients suffered previous surgery for ipsilateral peripheral coxa fracture that affected surgical protocol; (iii) patients were lost to follow-up within 24 months.

Patient Information

In this retrospective study, patients with valgus-impacted femoral neck fractures requiring surgery who underwent "in-out-in" percutaneous reduction technique and internal fixation were included as the percutaneous reduction group at a tertiary medical center in China between May 2017 and July 2020. This study was approved by the medical ethics committee of Ningbo No. 6 Hospital (X2022059), and all patients provided informed consent before participating in this study. Before surgery, each patient underwent routine examinations using standard radiography and CT with reconstruction. In total, 24 patients (seven men and 17 women) in the percutaneous reduction group completed the study and were included in the final outcome analysis. Furthermore, another 24 cases with valgus-impacted femoral neck fractures underwent *in situ* fixation were enrolled as control group for function comparison. All fractures were treated by one surgeon who had more than 15 years of experience in femoral neck fracture surgery. Surgical implants were provided by a single-device manufacturer (AO/Synthes Group Co., Ltd., USA). Postoperative assessments were performed by two surgical fellows. Patient demographics are provided in detail in Table 1.

Surgical Procedure

In Situ *Fixation Group*

Anesthesia and Position. After general endotracheal or spinal anesthesia, place the patient supine on an orthopaedic traction table with the lower extremities scissored (unaffected hip flexed and abducent relative to the injured side).

Closed reduction and internal fixation. Attempt closed reduction with orthopaedic traction table (Figure 1). Use fluoroscopy in both planes to confirm the fracture angulation. In patients with femoral neck presenting valgus-impacted status or posterior tilt, the deformity would be corrected by internal rotation and adduction of the affected leg. In the *in situ* group, three 7.3-mm partially threaded cannulated screws (AO/Synthes, USA) were used.

TABLE 1 Demographic characteristics and prognosis*

Indexes	Percutaneous reduction group (n = 24)	*In situ* fixation group (n = 24)	*t* value/ χ^2 value	*p* value
Age (y/o), mean (SD)	54.36 (10.95)	52.14 (11.23)	0.693	0.492
Male, n (%)	7 (29.16%)	10 (41.67)	0.82	0.365
Right side, n (%)	11 (49.11%)	12 (50%)	0.083	0.773
Valgus-impacted fractures with posterior tilt, n (%)	10 (41.67%)	13 (54.17%)	0.751	0.386
Valgus-impacted fractures without posterior tilt, n (%)	14 (58.33%)	11 (45.83%)		
Time from trauma to surgery (hr) ، mean (SD)	37.56 (15.91)	40.2 3 (18.55)	−0.535	0.595
Total follow-up (months), mean (SD)	29.96 (5.36)	31.25 (5.99)	−0.786	0.436
Smoker, n (%)	5 (20.83%)	6 (25%)	0.118	0.731
Hypertension, n (%)	7 (29.17%)	6 (25%)	0.105	0.745
Diabetes mellitus, n (%)	6 (25%)	8 (33.3%)	0.403	0.525
Harris hip score, mean (SD)				
6 months postoperatively	76 (6.72)	70.86 (6.91)	2.612	0.012*
1 year postoperatively	85.34 (6.33)	80 (6.11)	2.974	0.005**
2 years postoperatively	90.54 (5.81)	84.1 (7.82)	3.238	0.002**
Complications, n				
Fixation failure	1	0	0	1
Non-union	0	0		
Avascular necrosis	1	2		

* Demographic characteristics and prognosis in the two groups were recorded and compared (*$p < 0.05$, statistical significance between percutaneous reduction group and *in situ* fixation group).

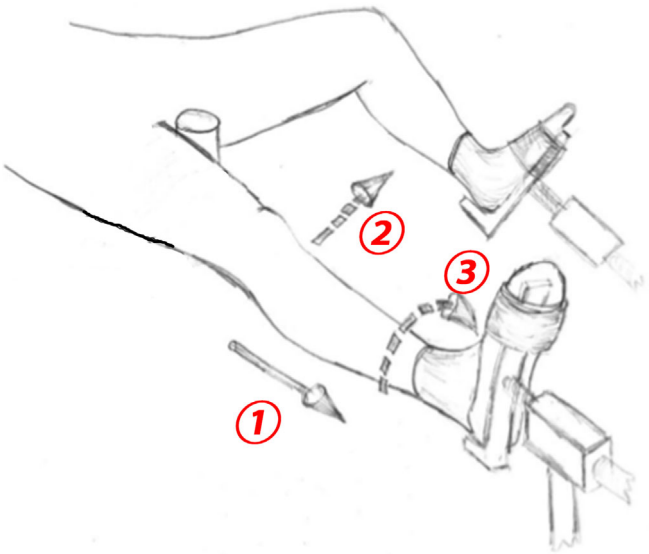

Fig. 1 Illustrative diagram of closed reduction technique. Before closed reduction, the affected limb is placed in position of slight flexion, abduction, and external rotation. Step 1, axial traction of the affected limb restores the length of the femoral neck. Step 2, appropriate adduction of the affected limb is performed. Step 3, internal rotation of the affected limb makes the patella facing upwards

Percutaneous Reduction Group

The surgical preparation and closed reduction were similar to those in the *in situ* fixation group. Next, "in-out-in" percutaneous reduction technique would be applied for remaining displacement. With the help of intraoperative fluoroscopy, a threaded Steinmann-pin would be drilled percutaneously, passing through the superior third of greater trochanter to the femoral head. In patients with valgus-impacted femoral neck fractures without posterior tilt of the femoral head, the tip of Steinmann-pin would be positioned at center of femoral head. If posterior tilt existed, Steinmann-pin would be inserted posteriorly, angling forward to the posterior third of femoral head (Figure 2). After satisfactory position of Steinmann-pin was ascertained by both planes of fluoroscopy, the end of Steinmann-pin would be gently hammered under fluoroscopy to achieve anatomical reduction (Figures 3 and 4). All patients were treated by percutaneous parallel cannulated screw fixation in a tri-angular configuration. Three cannulated screws (AO/Synthes, USA) with supero-anterior, supero-posterior, and infero-middle positions of femoral neck were advanced further across the fracture line within 5 mm from the subchondral bone. One screw with inferior position would be compressed properly and another two screws would be served as position screws without compression. Finally, Steinmann pin was removed.

Postoperative Care and Follow-Up

Antibiotic prophylaxis with cefuroxime was given on the day of surgery. Low-molecular-weight heparin was administered postoperatively during hospitalization and Rivaroxaban would be continued for 14 days after hospital discharge. The aim was to mobilize all patients on the first postoperative day under the supervision of a physiotherapist. Lower extremities, including hip, knee, and ankle joints, could be flexed and extended in sagittal plane on the bed. On the 3rd to 4th day, the affected limb could be assisted to the ground

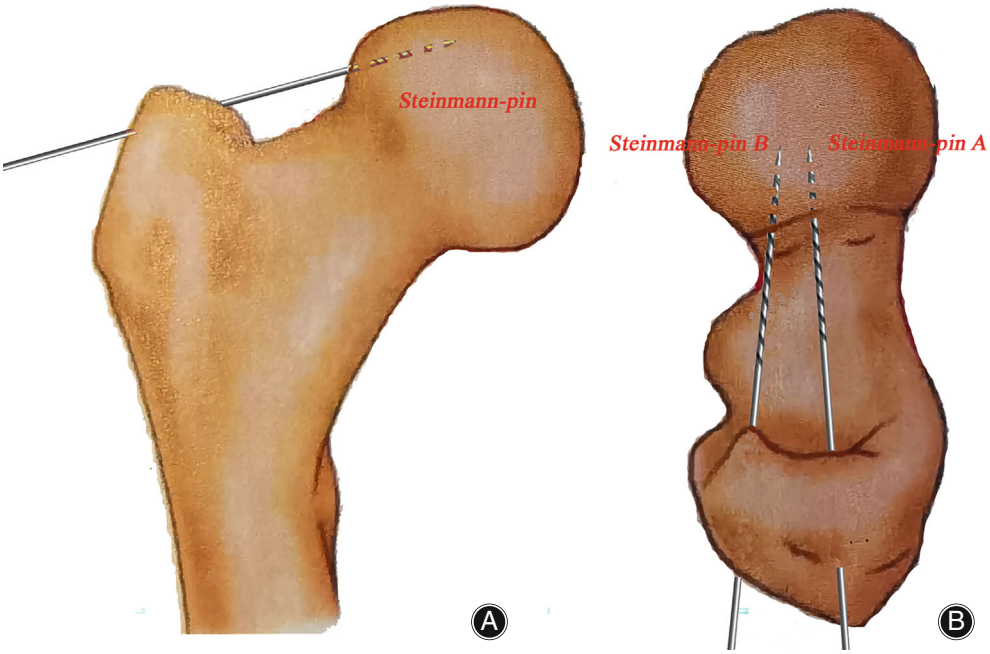

Fig. 2 Illustrative diagrams of positions of Steinmann pins for fracture reduction. (A) Anteroposterior view of position of Steinmann pin, which passes through the superior third of greater trochanter to the femoral head. (B) Lateral view of positions of Steinmann pins. Steinmann pin (A) In patients with valgus-impacted femoral neck fractures without posterior tilt, the pin is parallel with femoral neck and the tip is positioned at center of femoral head. Steinmann pin (B) In patients with posterior tilt existing, Steinmann pin is inserted posteriorly, angling forward to the posterior third of femoral head

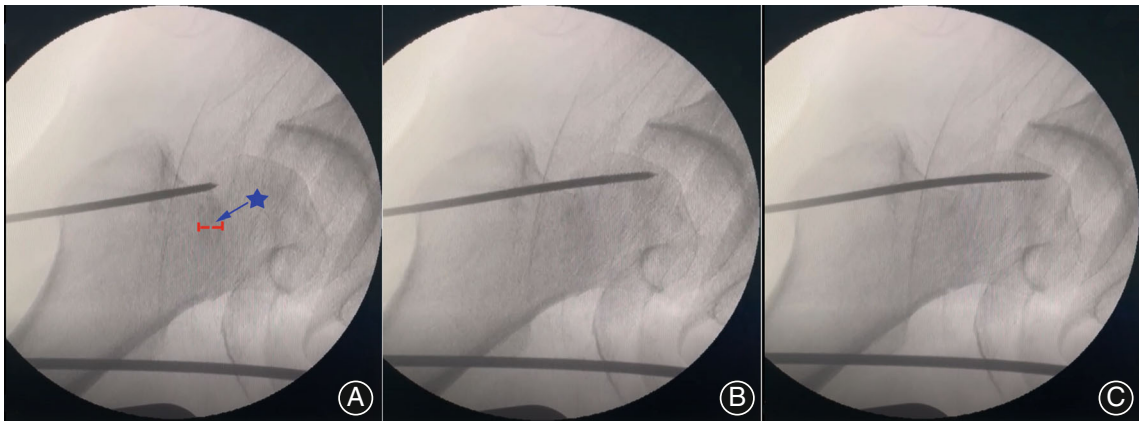

Fig. 3 Images of continuous intraoperative fluoroscopies at anteroposterior view. The end of Steinmann pin is gently hammered under fluoroscopy dynamically, achieving anatomical reduction of femoral neck fracture at image C. (Arrow: impacted part of the femoral neck fracture)

without weight bearing. Patients would be permitted for partial weight bearing until fracture healing by computed tomography (CT) scan. Generally, most patients would take full weight bearing 6 months after surgery. Muscle strengthening exercise, such as squats, lunges, or calf raises, would be permitted to perform with the aid of a physiotherapist in the next 6 months.

At the postoperative follow-up, all patients were assessed with X-rays and CT scan within 24 h. The reduction qualities of femoral neck fracture, including collodiaphyseal angle, posterior tilt angle[16] (Figure 4(B)), and amount of FNS[17] (Figure 5), were evaluated by two surgical fellows within 24 h, 6 months, and 2 years postoperatively. After discharge, patients were asked to visit the outpatient clinic regularly for imaging examinations and function evaluations (Harris Hip Score, HHS[18]). Furthermore, complications, such as fixation failure, non-union, and AVN, were identified by radiographs and symptoms until the final follow-up visit.

Statistics

Descriptive statistics were recorded and collated, and the mean and standard deviation for patient demographics and prognosis were calculated from the original dataset. Unpaired *t*-tests were used to compare patient demographics and prognosis between the two groups, while chi-square tests were used to measure the associations between the categorical data of the two groups. Differences were considered statistically significant at $p < 0.05$. In addition, the study

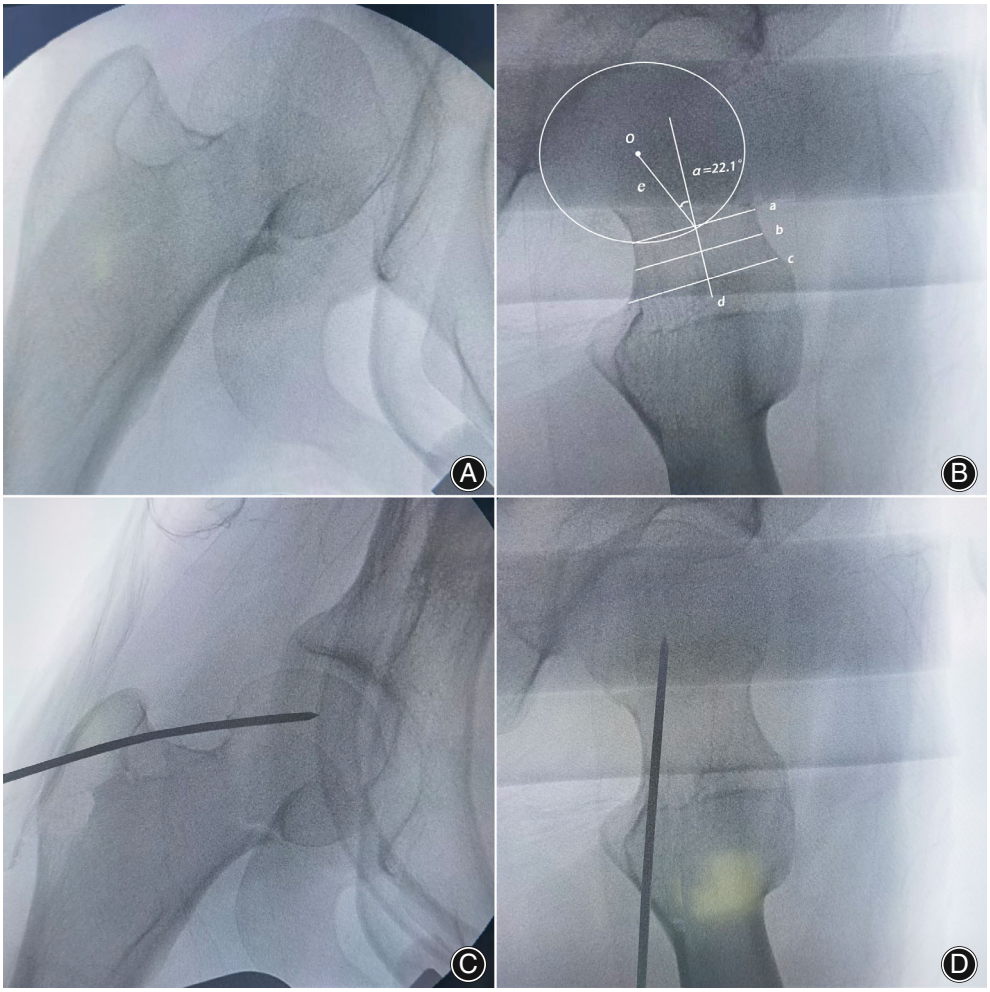

Fig. 4 Intraoperative fluoroscopy showing a case (female, 63 years old) of valgus-impacted femoral neck fracture with posterior tilt of femoral head before and after reduction within "in-out-in" percutaneous reduction technique. (A) Intraoperative anteroposterior view showing severe valgus-impacted femoral neck fracture. (B) Intraoperative lateral view showing severe posterior tilt of femoral head. The posterior tilt is measured as the angle (α) between the d line and the e line, which is drawn from the center (o) of the caput circle to the crossing of the caput circle and the *d* line. (C, D) Intraoperative fluoroscopy showing femoral neck fracture achieving reduction within "in-out-in" percutaneous reduction technique

utilized kappa test for the consistence of two independent observers in evaluating HHS for hip function and characterized kappa over 0.75 as excellent, 0.40 to 0.75 as fair to good, and below 0.40 as poor. All statistical analyses were performed using IBM SPSS Statistics for Windows, version 22.0 (IBM Corp, Armonk, NY).

Results

General Results

A total of 24 patients who underwent surgery using "in-out-in" percutaneous reduction technique in our institution were enrolled. A group of patients receiving *in situ* fixation was also included in the study for function comparison. Our minimum follow-up period was 2 years (range 24–42 months). Patients' preoperative data in two groups, including age, sex, affected side, fracture types, and medical history, were recorded and compared (Table 1). Preoperative demographic characteristics did not differ significantly between the groups ($p > 0.05$).

Radiographic Evaluation

Radiological parameters for reduction qualities of femoral neck fracture were measured and analyzed in the percutaneous reduction group. Collodiaphyseal angle, posterior tilt angle, and amount of FNS were significantly different between preoperative cases and immediately postoperative cases ($p < 0.05$). However, there were no statistical difference in the measurements among postoperative cases at different time points (within 24 h, 6 months, and 2 years postoperatively) ($p > 0.05$). (Table 2)

Clinical Prognosis

Bone union was achieved within 2 years postoperatively in all patients without non-union (Figure 6). In the percutaneous reduction group, AVN occurred in one patient at 2 years postoperatively and other patients were free of AVN at last follow-up. One patient suffered fixation failure with screws retreat but achieved bone union finally. In the *in situ* fixation group, two patients suffered AVN at last follow-up. Thus, three patients with AVN were excluded from the analysis of functional outcome and 45 patients were included in the

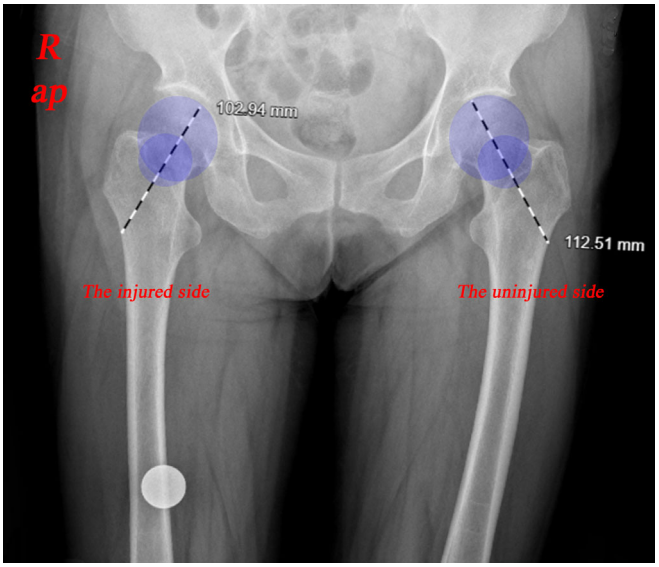

Fig. 5 Measurement of femoral neck shortening on anteroposterior radiographs of the pelvis. Draw a line passing the center of the femoral head and the center of the femoral neck. The length of line segment is from vertex of femoral head to lateral wall of femur. The femoral head shortening is defined as difference between the uninjured side and the injured side

function analysis. In evaluating functional outcomes of the hips by kappa analysis, the coefficient of consistence reached 0.814. It proved that the evaluation results are highly credible. The mean HHS at 6, 12, and 24 months after surgery were all better in percutaneous group (76 ± 6.72, 85.34 ± 6.33 and 90.54 ± 5.81) than that in the *in situ* fixation group (70.86 ± 6.91, 80 ± 6.11 and 84.1 ± 7.82), respectively ($p < 0.05$). (Table 1).

Discussion

The study introduces a novel technical trick for the treatment of valgus-impacted femoral neck fractures. According to radiological outcomes, "in-out-in" percutaneous reduction technique is safe and effective for satisfactory reduction of the fracture, avoiding femoral neck shortening and posterior tilt. And the clinical outcomes, evaluated by Harris Hip Score and complications after operation, show better functional outcomes in percutaneous reduction group, though the rates of complications are similar between the two groups.

Advantages of the Technique

Valgus-impacted femoral neck fracture is considered to be one type of stable fracture clinically. It was suggested that the treatment for this fracture was *in situ* internal fixation with parallel cannulated screws. Disimpaction may lead to instability and internal fixation failure.[19] However, more and more studies have reported that severe valgus-impacted deformities are associated with a higher incidence of complications, such as ischemic necrosis and functional limitation.[7,11,17,20] Furthermore, posterior tilt of the femoral head, usually as a concomitant of the valgus-impacted femoral neck fracture, is another high risk leading to poor outcomes.[12,16,21,22] As a result, restoration to the normal anatomy is important in valgus-impacted femoral neck fracture, especially with severe posterior tilt.

Reduction Quality of the Femoral Neck Fractures

In clinical practice, closed reduction and traction technique alone often fails to correct impacted deformity and posterior tilt. Open reduction will further increase trauma and blood supply of the femoral head. Therefore, our technique tried to obtain anatomical reduction of the fracture with minimal invasion. Results of valgus-impacted femoral neck fracture treated with "in-out-in" percutaneous reduction technique have shown promising results in the study. Radiological parameters, including collodiaphyseal angle, posterior tilt angle, and amount of FNS, achieved effective improvements immediately after surgery and maintained favorable outcome during follow-up. In terms of functional outcomes, functional deficits were lesser in the percutaneous reduction group than in the *in situ* fixation group. Previous studies[11,17,20,23] reported the significance of FNS after femoral neck fractures and its relationship with functional outcomes. In short, femoral neck shortening >5 mm was associated with significantly lower function score, which is similar to the findings of our study. Furthermore, severe posterior tilt (>20°) is associated with a significantly increased risk of surgical failures.[12,13] A study by Kanu *et al.*[12] showed 22.4% patients with posterior tilt

TABLE 2 Radiological outcomes of case series [Mean (SD)]*

Indexes	Preoperation	Postoperative within 24 hr	6 months postoperative on	2 years postoperative on
Collodiaphyseal angle (°),	149.52 (7.56)	129.77 (5.22)*	132.13 (4.85)	133.02 (4.88)
Posterior tilt angle (°),	16.46 (8.91)	8.08 (4.78)*	8.78 (4.52)	8.79 (4.34)
Femoral neck shortening (mm),	8.93 (0.84)	1.62 (1.51)*	2.24 (1.66)	2.54 (1.75)

* Radiological outcomes were recorded and compared (*$p < 0.05$, statistical significance between preoperative measurements and postoperative measurements within 24 hr in the percutaneous reduction group).

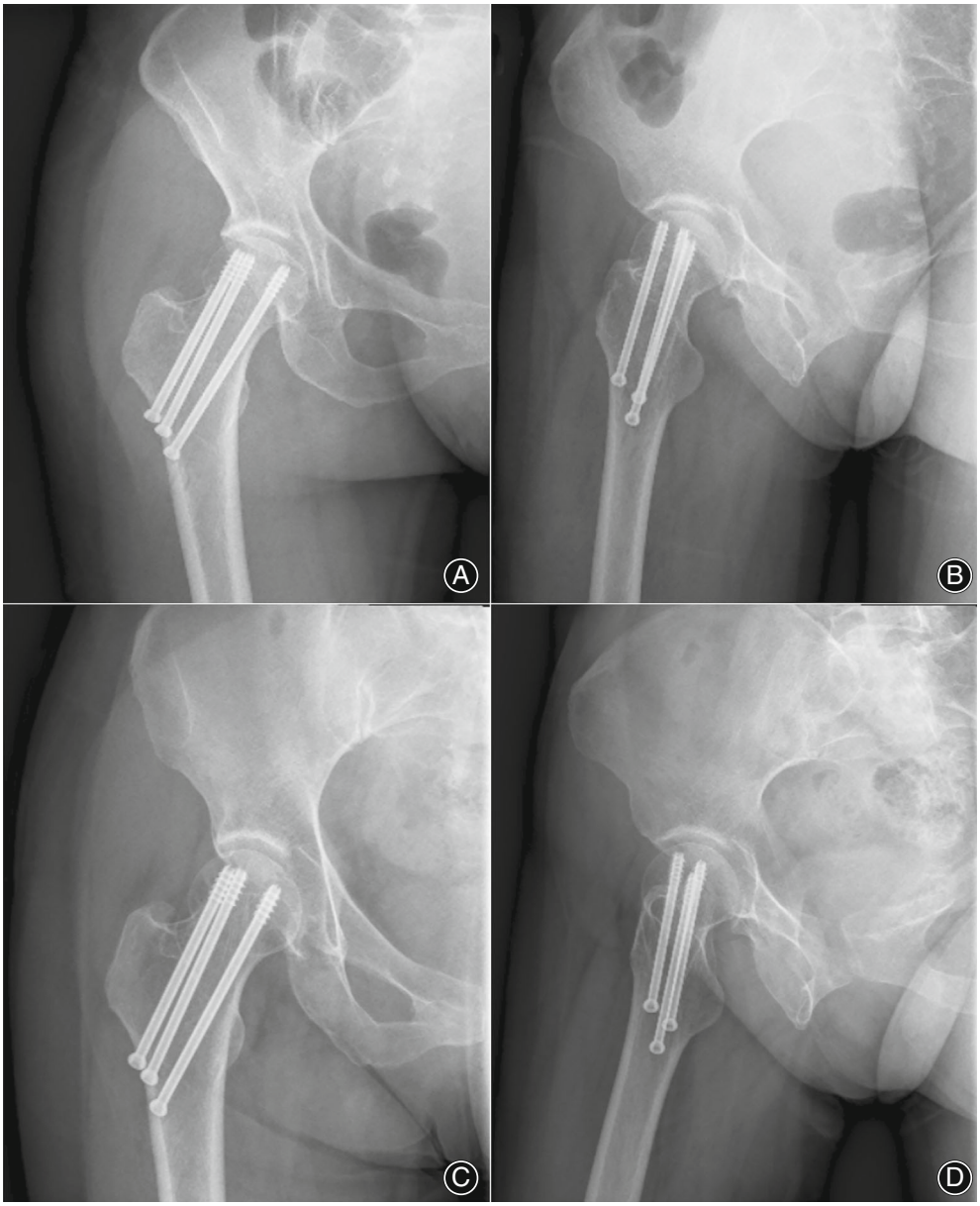

Fig. 6 Images of postoperative radiographs within 24 h (A and B) and at 24 months after surgery (C and D) showing a case (female, 63 years old) of valgus-impacted femoral neck fracture achieving anatomical reduction and union

>20° underwent subsequent arthroplasty, compared with 11.9% patients with posterior tilt <20°. In the study, the technique could achieve satisfactory reduction in valgus-impacted deformity as well as posterior tilt, which might help reduce the risk of complications theoretically. Forty-five patients obtained satisfactory outcomes besides three patients developing AVN, one in the percutaneous reduction group and two in the *in situ* fixation group. One patient suffered fixation failure with screws retreat within 3 months due to osteoporosis and early weight bearing but achieved bone union finally. Thus, early weight bearing should be forbidden when valgus-impacted deformity is corrected, especially in osteoporotic patients. Several studies[24–26] reported that hemarthrosis leading to increased intracapsular pressure after femoral neck fracture is suspected to impair blood flow to the femoral head and may lead to osteonecrosis. "In-out-in" technique pierces the capsula articularis coxae and restores the length of femoral neck, which may reduce intracapsular pressure to be a protection for the femoral head, theoretically.

Key Points during Operation

The technique has several key points. Firstly, we recommend Steinmann pin possessing thread at pin tip as a reduction tool for surgery. After drilled at the ideal position, the threaded Steinmann pin may provide larger holding force to

make disimpaction of the fracture. Secondly, the position of the Steinmann pin depends on whether posterior tilt exists. In patients with valgus-impacted femoral neck fractures without posterior tilt of the femoral head, the tip of Steinmann pin will be positioned at center of femoral head. If posterior tilt exists, Steinmann pin will be inserted posteriorly, angling forward to the posterior third of femoral head. Intraoperative fluoroscopy is required for the Steinmann pin's position and forward trend in the superior third of greater trochanter. Steinmann pin adjustment in greater trochanter part is relatively safe. Furthermore, the medial femoral circumflex artery is the main vascular supply, with the majority of femoral head perfusion achieved through the superior retinacular artery. This artery and its terminal branches are closely associated with the femoral neck.[27] The tip may avoid injuring femoral circumflex artery when Steinmann pin is away from femoral neck. It is a significant step determining success of the surgery and vascular safety. Thirdly, Steinmann pin should be hammered gently under fluoroscopy dynamically to prevent penetration of the femoral head. And fourthly, after achieving ideal reduction of the fracture, Steinmann pin should remain as a temporary fixation and a locating pin until percutaneous parallel cannulated screws insert.

Strengths and Limitations

This is the first study describing "in-out-in" technique in treating patients with valgus-impacted femoral neck fractures with or without posterior tilt. In this retrospective study, 24 patients were followed up for at least 2 years with complete and reliable radiological data and functional evaluation. Furthermore, another 24 cases with *in situ* fixation were enrolled as control group for function comparison, which showed evident function improvement in "in-out-in" technique reduction group. The study summarized key points during operation and intermediate prognosis, which may provide some guidance in clinical practice.

This technique has its own limitations. The operation may require more radiation exposure to achieve favorable reduction, especially in inexperienced surgeons. Furthermore, the ideal position of Steinmann pin depends on surgeon's decision, especially when posterior tilt exists. There are no objective criteria to estimate the exact location of the tip. Moreover, we focused on several key points to minimize the vascular injury as described above. And the prognosis is favorable so far. However, further research with exact vascular problem and injury rates in "in-out-in" technique is required. The period from surgery to the final follow-up was not similar in every case, which may have affected the radiological evaluation results. Further multicenter studies with more patients and long-term follow-up are needed to estimate the surgical technique.

Conclusion

In patients of valgus-impacted femoral neck fractures with or without posterior tilt, "in-out-in" percutaneous reduction technique is safe and effective for achieving anatomical reduction, which restores the femoral neck length. Additionally, successful bone union and satisfactory function are achieved through fixation after reduction, according to the follow-up of the case series.

Acknowledgement

None.

Authors' Contributions

Jianlei Liu made the substantial contributions to the conception and design of the work; Tianming Yu acquired and collected data for the work and drafted the manuscript; Jichong Ying analyzed the data; Yunqiang Zhuang revised it critically for important intellectual content; Jianlei Liu made the final approval of the version to be published; and all authors agreed to be accountable for all aspects of the work, whose questions related to the accuracy or integrity of any part of the work were appropriately investigated and resolved.

Conflicts of Interest

None.

Disclosure Statement

All authors certify they have not signed any agreements with a commercial interest related to this paper which would in any way limit publication of any and all data generated for the paper or to delay publication for any reason.

Ethics Statement

The study was approved by the medical ethics committeeof Ningbo No. 6 Hospital (X2022059), and all patients provided informed consent before participating in this study.

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