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CLINICAL ARTICLE

Comparison of the Effect of Rhombic and Inverted Triangle Configurations of Cannulated Screws on Internal Fixation of Nondisplaced Femoral Neck Fractures in Elderly Patients

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Objective: To investigate whether four-screw fixation in rhombic configuration could improve the clinical outcomes and decrease the complication rate compared with three-screw fixation in inverted triangle configuration in elderly patients with nondisplaced femoral neck fractures.

Method: From January 2018 to January 2019, 91 elderly patients with nondisplaced femoral neck fractures who were treated with a cannulated screw system were reviewed retrospectively. The inverted triangle configuration was applied in 51 patients and rhombic configuration in 40 patients. The demographic and perioperative information of the patients were extracted from medical records and surgical records. Variables including incision size, surgical blood loss, surgical time, fluoroscopy time, hospital stays, fracture union time, postoperative visual analogue scale (VAS) scores, and complications were compared between the two groups. Also, Harris hip score at the final follow-up was used to evaluate the functional outcomes.

Results: All patients were followed up from 24 to 36 months, with an average of 29.75 months. The average age of patients was 72.37 ± 7.16 years. No significant differences were found between the two groups with regard to patients' age, gender, affected side, Garden classification, Pauwels classification and comminution of posterior wall ($P > 0.05$). We found shorter incision size ($P < 0.001$), less blood loss ($P = 0.020$), less surgical time ($P = 0.026$), and shorter fluoroscopy time ($P < 0.001$) in inverted triangle configuration group. However, shorter hospital stays ($P = 0.001$) and fracture union time ($P = 0.002$) were found in the rhombic configuration group. The VAS scores were lower in the rhombic configuration group at the first ($P < 0.001$) and third months ($P = 0.010$), but no significant difference was found at the sixth month ($P = 0.075$). Meanwhile, the total complication rate was relatively lower in the rhombic configuration group compared to the inverted triangle configuration group ($P = 0.041$). Harris hip score presented no significant difference between the two groups at final follow-up ($P = 0.078$). No wound infection or cortical perforation occurred in either group.

Conclusion: Four-screw fixation in rhombic configuration was superior to three-screw fixation in inverted triangle configuration in the treatment of nondisplaced femoral neck fractures in elderly patients in terms of less early postsurgical pain, shorter fracture union time, and lower complication rate.

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Introduction

Femoral neck fractures often occur in the elderly population and account for 3.13% of all fractures and nearly half of hip fractures in adults[1–3]. With the increase of life expectancy and development of medical technology, the incidence of this injury would rise year by year. It is estimated that the number of femoral neck fractures worldwide will over 3.9 million by 2050[1,2,4,5]. Owing to advanced age and concomitant underlying diseases (heart disease, diabetes mellitus, pulmonary disease, cerebrovascular disease) or limb immobilization after trauma, elderly patients with femoral neck fractures are prone to developing various complications after non-operative treatment, such as painful bed sores, deep vein thrombosis and depression, which would make the already poor prognosis further exacerbated[6,7]. Therefore, surgical treatment is proposed for those patients to restore the normal range of motion so as to perform daily activities as earlier as possible.

Numerous surgical procedures have been recommended to treat femoral neck fractures, including arthroplasty, cannulated screw system, dynamic hip screw, dynamic condylar screw, and proximal femoral nail antirotation[8]. Currently, it is generally accepted that arthroplasty should be used for displaced femoral neck fractures in elderly patients.[9] However, the optimal management of nondisplaced elderly femoral neck fractures remains controversial. Though arthroplasty had several advantages, such as improved mobility and fewer major reoperations, it was reported that there was no significant difference between internal fixation and arthroplasty in long-term mortality and reestablishing hip functions.[9,10]. Besides, the result of a successful hip replacement is not exactly equivalent to a united femoral neck fracture, especially in Chinese elderly patients who like squatting or sitting cross-legged. Therefore, the hip preservation should be performed as much as possible in elderly patients with nondisplaced femoral neck factures.

Due to minimally invasive, easy manipulation, and limited interference of the femoral head blood supply, the cannulated screw system has become the preferred treatment for nondisplaced femoral neck fractures, especially the inverted triangle configuration.[11–13]. Although there is a general consensus on the benefits of cannulated screw fixation for femoral neck fractures, the complication rate is still a concern. It has been reported that the complication rate after fixation of femoral head fractures by cannulated screw system was up to 20%–48%, including femoral head necrosis, nonunion, and reoperation.[14–17]. Besides, fixation with three cannulated screws usually causes a tendency toward screw exit accompanied by femoral neck shortening, which would have a significant negative impact on the hip function[18]. Therefore, in order to reduce the complication rate and improve fracture stability, different numbers and configuration of cannulated screws have been explored by researchers[19,20]. In a biomechanical study, Kauffman *et al.* showed that improved rigidity and fixation strength could be obtained by four screws compared with three screws for fixation of femoral neck fractures[21]. In contrast, some authors have drawn a different conclusion. Guo *et al.* reported that four-screw fixation could not improve the clinical outcomes and decrease complications in younger patients with femoral neck fractures[22]. It is not clear whether adding a fourth screw and changing the screws configuration would improve the prognosis of nondisplaced femoral neck fractures in elderly patients. Especially, most elderly patients with femoral neck fractures have osteopenia or osteoporosis, which could result in a high failure rate of internal fixation[23,24]. To our knowledge, there is a lack of study to discuss the clinical efficacy between different numbers and configurations of cannulated screws for fixation of elderly nondisplaced femoral neck fractures in current literature.

On the basis of this, we retrospectively analyzed 91 elderly patients with nondisplaced femoral neck fractures who underwent cannulated screw fixation in either rhombic configuration or inverted triangle configuration for a minimum follow-up of 2 years. The aims of this study were to: (i) compare the clinical outcomes and postoperative complications between the rhombic configuration and inverted triangle configuration; and (ii) evaluate the practicability of four-screw fixation in rhombic configuration.

Methods

Study Design

This was a retrospective cohort study. From January 2018 to January 2019, consecutive elderly patients undergoing closed reduction and cannulated screw fixation for acute nondisplaced femoral neck fractures were reviewed. According to the configuration of cannulated screws, the patients were divided into inverted triangle configuration group and rhombic configuration group. This study was performed according to the Declaration of Helsinki and the Review Board of the Third Hospital of Hebei Medical University has approved it (NO 2020-040-01). All patients or their legal guardians provided the informed consent.

Inclusion and Exclusion Criteria

The inclusion criteria were: (i) patients older than 65 years with an acute nondisplaced femoral neck fracture (Garden I or II); (ii) patients who were treated with closed reduction and cannulated screw fixation; (iii) the configurations of cannulated screws were considered as the comparison; and (iv) patients with complete follow-up outcomes and follow-up time ≥24 months. The definition of acute femoral neck fracture was a fracture treated within 3 weeks of occurrence[25].

The exclusion criteria were as follows: (i) presence of severe cognitive dysfunction; (ii) pathological fracture;

(iii) history of ipsilateral femoral neck fracture or revision surgery; and (iv) treated with other internal fixations.

As presented in Fig. 1, a total of 91 patients with a diagnosed of non-displaced femoral neck fracture were included in our study.

Surgical Technique

Anesthesia and Position

All operations were performed under general or spinal anesthesia which was decided by the anesthesiologist. Patients were placed on a traction table in the supine position.

Approach and Exposure

Under fluoroscopy, a guide pin was inserted with attaching to the femoral calcar as close as possible and paralleling to the femoral neck axis in the anteroposterior view. In the lateral view, the guide pin should be located at the center of the femoral neck and paralleled to the anteversion angle. Then, a second guide pin was placed close to the upper margin of the femoral neck. Subsequently, according to the position of the two guide pins, the third and fourth guide pins were inserted close to the anterior and posterior cortex of the femoral neck. The four guide pins formed a rhombic shape. Of note, all the head of guide pins were 5 mm under the femoral head surface. Finally, four partial cancellous threaded cannulated compression screws (6.5-mm; Stryker, Kalamazoo, MI, USA) were inserted along the guide pins (Fig. 2A,B). After ensuring the quality of reduction in the anteroposterior and lateral views, the incision was closed.

In the inverted triangle configuration group, the first guide pin was placed under fluoroscopy with the same method as above. Then, paralleled to the longitudinal axis of the femoral neck, the second and third guide pins were inserted, which were located at the anterior and posterior superior directions of the femoral neck. The three guide pins formed an inverted triangle configuration. After depth measurement, three partial cancellous threaded cannulated screws (6.5-mm; Stryker, Kalamazoo, MI, USA) of appropriate length were selected for fixation (Fig. 2C,D). After ensured the quality of reduction and irrigated the wound, the incision was closed.

Postoperative Management

All patients received antibiotic prophylaxis (2.0 g cefazolin) 30 min prior to surgery, as well as low molecular-weight heparin once daily for 2 weeks as antithrombotic prophylaxis. Stitches were taken out at 2 weeks after surgery. Passive range-of-motion exercises of knee and hip joints were performed for the first 24 h after the operation. Partial weight-bearing ambulation with crutches was started at 2 weeks postoperatively while full weight-bearing was allowed after fracture union.

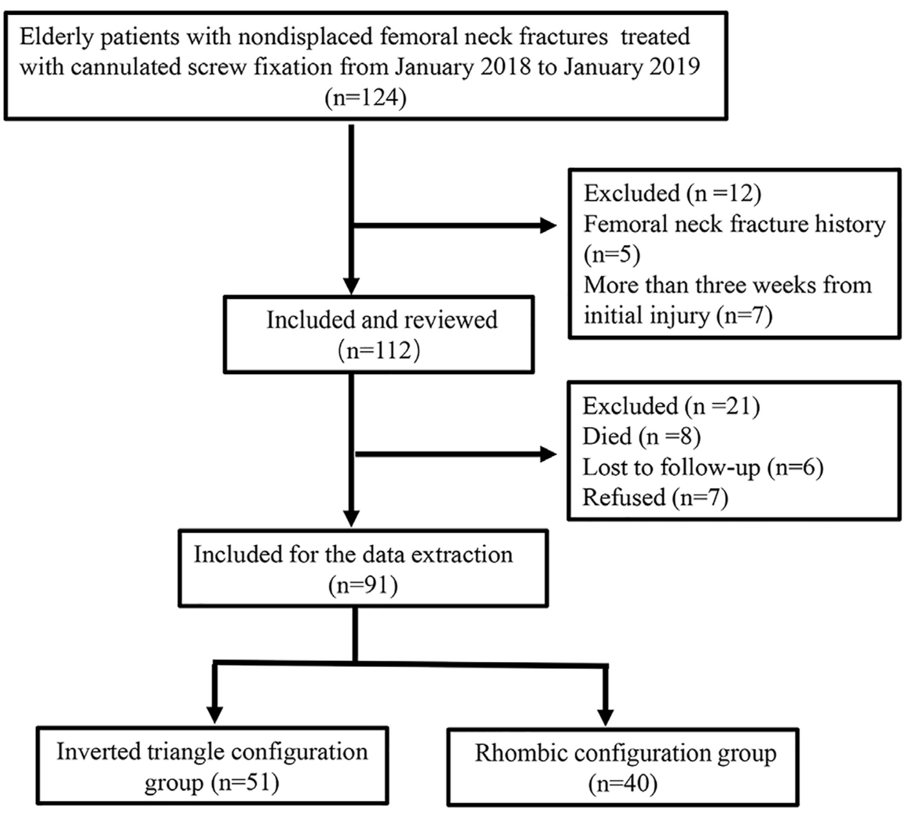

Fig. 1 The flowchart of participants selection.

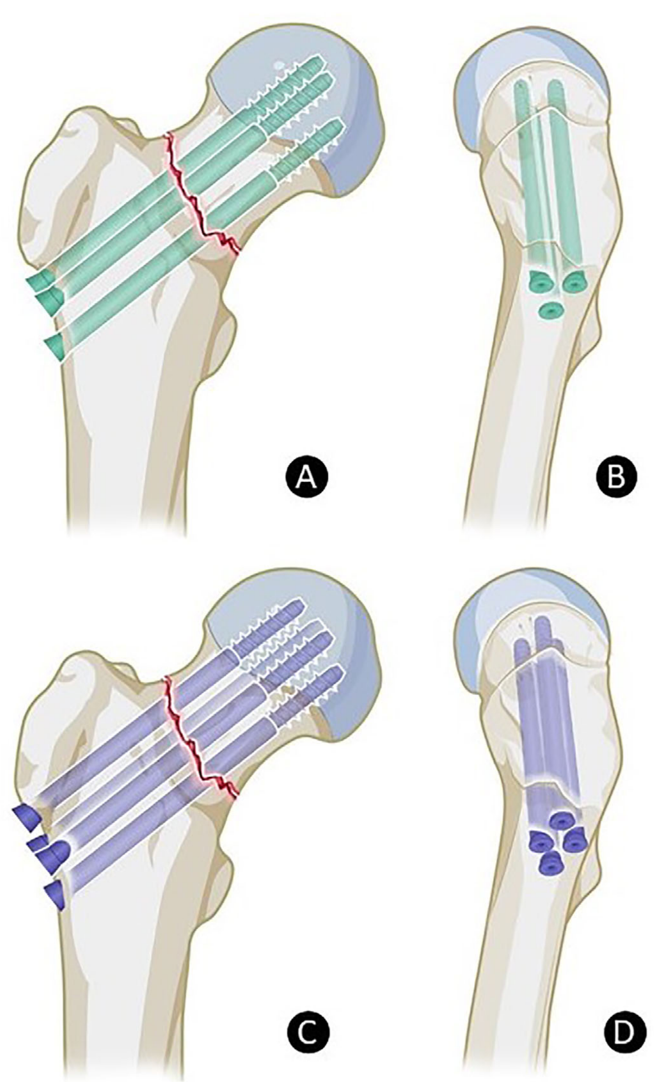

Fig. 2 Schematic illustration showing that femoral neck fractures were fixed with cannulated screws in different configurations. (A, B) Inverted triangle configuration in anteroposterior and lateral view; (C, D) Rhombic configuration in anteroposterior and lateral view.

Outcome Measurements

The patients were followed up at 1, 3, 6, 12, and 24 months after the primary operation. The detailed variables of interest were categorized into three aspects.

Demographic and Fracture-Related Variables

Demographic variables were as follows: age (years), gender, and Charlson's age-comorbidity index (CACI). CACI is the most commonly used method to evaluate the severity of comorbidities in elderly patients. It is calculated based on the patient's medical history, prognosis and weighted age[26]. Fracture-related variables included affected side, Garden classification, Pauwels classification and comminution of posterior wall.

Preoperative and Intraoperative Variables

Preoperative and intraoperative variables included incision size (cm), time to surgery (days), hospital stays (days), surgical blood loss (mL), surgical time (mins), time of fluoroscopic examinations (mins), types of anesthesia, and the American Society of Anesthesiologists classification. The types of anesthesia were divided into general anesthesia and regional anesthesia. The latter included spinal and epidural anesthesia.

Clinical Outcomes and Complications

The clinical outcomes included Harris hip score (scale of 1–100) at the end of follow-up and visual analogue scale (VAS: 0, no pain;10, worst possible pain imagined) at the first, third, and sixth month postoperatively. Besides, the fracture union time (weeks) was also recorded.

Complications included wound infection, cortical perforation, avascular necrosis, fracture non-union, screw exit and cut-out. A radiographic lucency or persistent fracture line over 12 months without progressive healing was considered as nonunion.

Statistics

Analyses used SPSS software (SPSS v25, SPSS Inc., Chicago, IL, USA). Count data were described as mean $\pm$ standard deviation (SD), and categorical data were showed as numbers. The Shapiro–Wilk test was used to evaluate distribution of count data for normality. A Mann–Whitney U-test or Student t-test was utilized to compare count data while Pearson's chi-square or Fisher's exact test for categorical data. A $P < 0.05$ was considered as statistically significant difference.

Results

Follow-Up

All patients in both the inverted triangle configuration group and rhombic configuration group completed the follow-up by medical history review, outpatient follow-up, and questionnaire survey. The mean follow-up time was 29.75 months with a range from 24 to 36 months.

General Results

The general demographic information of included patients are presented in Table 1. Of all the patients, 51 were treated with three-screw fixation in inverted triangle configuration and 40 patients were treated with four-screw fixation in rhombic configuration. Three typical cases were presented in Figs 3, 4, and 5. The average age of patients was 72.37 $\pm$ 7.16 years (25 [27.5%] men and 66 [72.5%] women). There was no statistical difference between the two groups in age ($P = 0.364$), gender ($P = 0.996$), affected side ($P = 0.735$), Garden classification ($P = 0.592$), Pauwels classifications ($P = 0.784$) and comminution of posterior wall ($P = 0.526$). However, compared with inverted triangle

Table 1 Summary of demographic data

Variables	Inverted triangle group ($n = 51$)	Rhombic group ($n = 40$)	Statistical value	P value
Age (mean ± SD, years)	71.73 ± 6.76	73.20 ± 7.364	$Z = -0.908$	0.364[a]
Gender(male/female)	14/37	11/29	$\chi^2 = 0.000$	0.996[b]
CACI (mean ± SD)	3.43 ± 1.59	4.30 ± 1.56	$Z = -2.965$	0.003[a]
Side (left/right)	34/17	28/12	$\chi^2 = 0.115$	0.735[b]
Follow-up time (mean ± SD, months)	29.12 ± 3.93	30.55 ± 3.47	$Z = -1.846$	0.065[a]
Garden classification			$\chi^2 = 0.288$	0.592[b]
I	8	8		
II	43	32		
Pauwels classification			$F = 0.656$	0.784[c]
I	4	5		
II	27	21		
III	20	14		
Comminution of posterior wall (yes/no)	5/46	6/34	-	0.526[c]

Abbreviation: CACI, Charlson's age-comorbidity Index.; [a] Mann–Whitney U-test.; [b] Pearson Chi-Square test.; [c] Fisher's exact test.

configuration group, patients in rhombic configuration group had higher CACI (4.30 ± 1.56 *vs* 3.43 ± 1.59, $P = 0.003$), suggesting that this group of patients had more or severer underlying diseases.

Preoperative and Intraoperative Outcomes

Preoperative and intraoperative outcomes are shown in Table 2. Although there was no statistical difference in anesthesia type ($P = 0.700$) and the American Society of Anesthesiologists classification ($P = 0.056$) between the two groups, the hospital stays were shorter in rhombic configuration group (9.28 ± 5.69 *vs* 11.51 ± 4.42, $P = 0.001$). Mean surgical time was 12 min longer in rhombic configuration group (90.75 ± 28.52 *vs* 78.43 ± 26.45, $P = 0.026$). Meanwhile, shorter incision size (5.20 ± 1.63 *vs* 6.56 ± 1.48, $P < 0.001$), less blood loss (63.33 ± 29.73 *vs* 75.50 ± 26.33, $P = 0.020$) and fluoroscopy time (23.80 ± 7.07 *vs* 29.40 ± 6.48, $P < 0.001$) was observed in inverted triangle configuration group. As for time to surgery, there was no difference between the two groups ($P = 0.070$).

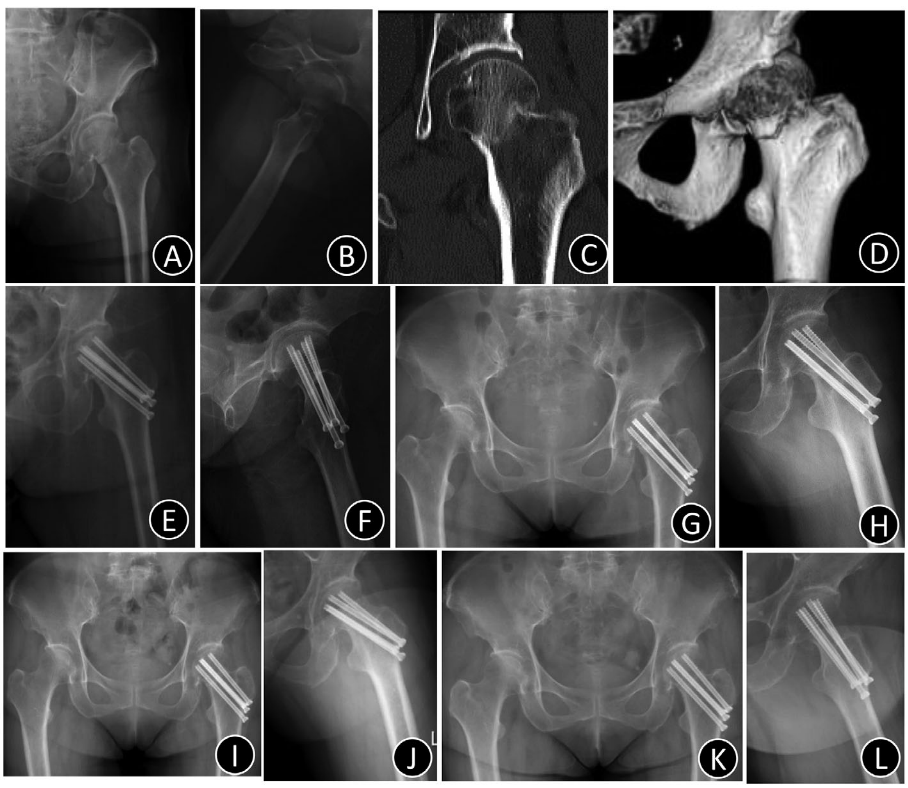

Fig. 3 Imaging examination of a 67-year-old woman with nondisplaced femoral neck fracture fixed with four screws in rhombic configuration. (A, B) Preoperative anteroposterior and lateral radiographs of left hip joint. (C, D) Preoperative two-dimensional and three-dimensional computed tomography reconstruction. (E, F) Postoperative anteroposterior and lateral views. (G, H) Anteroposterior and lateral radiographs 3 months postoperatively. (I, J) Anteroposterior and lateral views 12 months postoperatively. (K, L) Postoperative anteroposterior and lateral radiographs at 24 months showed no failure of internal fixation and osteonecrosis of the femoral head.

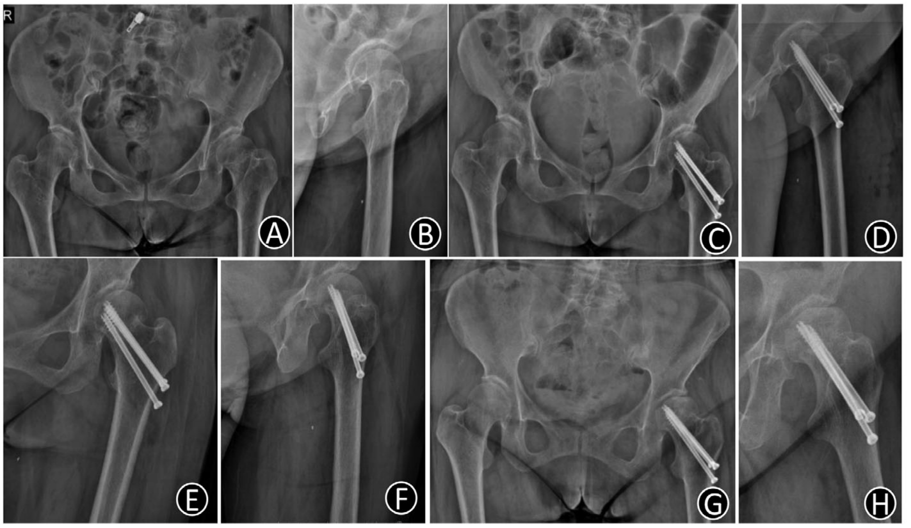

Fig. 4 A 65-year-old female patient had the femoral head necrosis after fixation of the femoral neck fracture with three screws in inverted triangle configuration. (A, B) Preoperative anteroposterior and lateral radiographs of left hip joint. (C, D) Postoperative anteroposterior and lateral views. (E, F) Anteroposterior and lateral radiographs 3 months postoperatively. (G, H) Anteroposterior and lateral projections at 24 months postoperatively showed osteonecrosis of the femoral head and had not undergone arthroplasty.

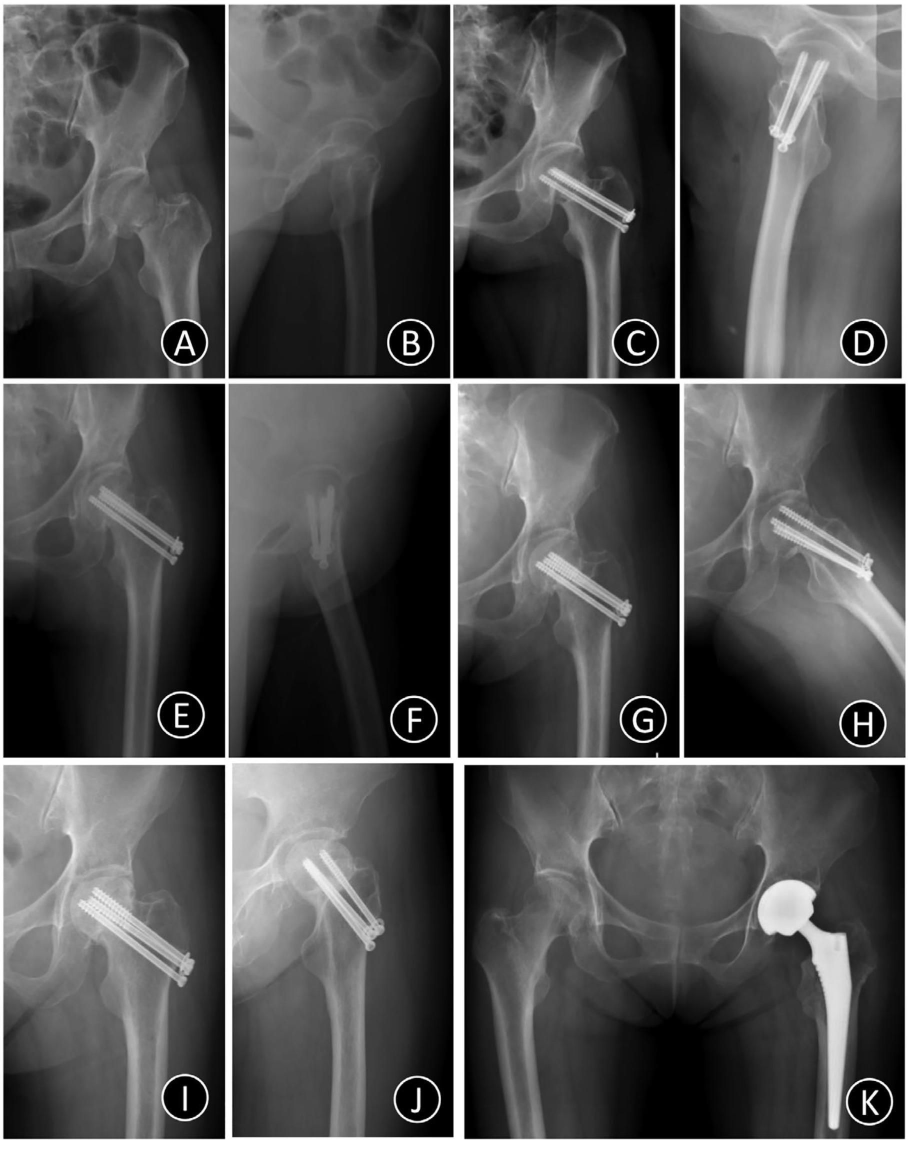

Fig. 5 A 66-year-old female patient had nonunion of femoral neck after three-screw fixation in inverted triangle configuration. (A, B) Preoperative anteroposterior and lateral radiographs of left hip joint. (C, D) Postoperative anteroposterior and lateral views. (E, F) Anteroposterior and lateral radiographs six months postoperatively. (G, H) Anteroposterior and lateral projections at 12 months after surgery showed nonunion of femoral neck fracture. (I, J) Anteroposterior and lateral projections at 24 months after operation showed osteonecrosis of the femoral head and underwent hip arthroplasty (K).

TABLE 2 Preoperative and intraoperative variables comparison

Variables	Inverted triangle group ($n = 51$)	Rhombic group ($n = 40$)	Statistical value	P value
Incision size (mean ± SD, cm)	5.20 ± 1.63	6.56 ± 1.48	$t = -4.082$	<0.001[a]
Surgical blood loss (mean ± SD, ml)	63.33 ± 29.73	75.50 ± 26.33	$Z = -2.325$	0.020[b]
Surgical time (mean ± SD, min)	78.43 ± 26.45	90.75 ± 28.52	$Z = -2.227$	0.026[b]
Anesthesia types			$\chi^2 = 0.149$	0.700[c]
General anesthesia	11	10		
Regional anesthesia	40	30		
ASA classification			$\chi^2 = 3.654$	0.056[c]
I-II	45	29		
III-IV	6	11		
Fluoroscopy time (mean ± SD, min)	23.80 ± 7.07	29.40 ± 6.48	$t = -3.888$	<0.001[a]
Time to surgery (mean ± SD days)	3.57 ± 2.50	4.50 ± 2.28	$t = -1.834$	0.070[a]
Hospital stays (mean ± SD days)	11.51 ± 4.42	9.28 ± 5.69	$Z = -3.232$	0.001[b]

Abbreviation: ASA, American Society of Anesthesiologists.; [a] Student *t*-test.; [b] Mann–Whitney *U*-test.; [c] Pearson Chi-Square test.

TABLE 3 Subgroup analysis of rhombic configuration group

Variables	Males ($n = 11$)	Females ($n = 29$)	Statistical value	P value
Age (mean ± SD, years)	74.73 ± 9.29	72.62 ± 7.01	$Z = -0.335$	0.443[a]
CACI (mean ± SD)	5.00 ± 1.79	4.03 ± 1.40	$Z = -1.647$	0.079[a]
Incision size (mean ± SD, cm)	6.51 ± 1.84	6.57 ± 1.35	$t = -0.120$	0.905[b]
Surgical blood loss (mean ± SD, ml)	75.00 ± 29.58	75.69 ± 25.56	$Z = -0.076$	0.942[a]
Surgical time (mean ± SD, min)	90.91 ± 34.92	90.69 ± 26.41	$Z = -0.031$	0.983[a]
Fluoroscopy time (mean ± SD, min)	27.09 ± 4.78	30.28 ± 6.88	$t = -1.406$	0.168[b]
Time to surgery (mean ± SD, days)	4.82 ± 1.60	4.38 ± 2.50	$t = 0.540$	0.593[b]
Hospital stays (mean ± SD, days)	10.27 ± 6.00	8.90 ± 5.63	$Z = -0.796$	0.502[a]
Harris hip score (mean ± SD)	82.73 ± 6.08	83.10 ± 6.44	$t = -0.167$	0.868[b]
Fracture union time (mean ± SD, weeks)	14.02 ± 2.42	13.23 ± 1.48	$t = 1.009$	0.332[b]
VAS score (mean ± SD)				
1 month	3.55 ± 1.75	3.52 ± 1.64	$Z = -0.015$	0.962[a]
3 months	2.00 ± 1.18	1.90 ± 1.18	$Z = -0.281$	0.805[a]
6 months	1.09 ± 0.83	1.10 ± 0.82	$Z = -0.032$	0.966[a]

Abbreviations: CACI, Charlson's age-comorbidity Index; VAS, visual analogue scale.; [a] Mann–Whitney *U*-test.; [b] Student *t*-test.

Subgroup Analysis

In the rhombic configuration group, no statistical difference was found between different genders in age ($P = 0.443$), CACI ($P = 0.079$), incision size ($P = 0.905$), surgical blood loss ($P = 0.942$), surgical time ($P = 0.983$), fluoroscopy time ($P = 0.168$), time to surgery ($P = 0.593$), hospital stays ($P = 0.502$), Harris hip score ($P = 0.868$), fracture union time ($P = 0.332$), and postoperative VAS score ($P > 0.05$) (Table 3).

Clinical Outcomes

No statistically significant difference was observed in Harris hip score ($P = 0.078$) between the two groups at final follow-up (Table 4). Patients in rhombic configuration group had shorter fracture union time compared with those in inverted triangle configuration group (13.45 ± 1.79 *vs* 14.47 ± 1.29, $P = 0.002$).

The VAS score was higher in the inverted triangle group than the rhombic group in the first month (5.16 ± 1.75 *vs* 3.53 ± 1.65, $P < 0.001$) and the third month (2.86 ± 1.77 *vs* 1.93 ± 1.16, $P = 0.010$) while no significant difference was found at the sixth month (1.45 ± 0.99 *vs* 1.10 ± 0.81, $P = 0.075$).

Complications

The postoperative complications were found in 15 patients, including three in the rhombic configuration group and 12 in the inverted triangle configuration group. As a result, there was a significant difference between the two groups in terms of total postoperative complications (3/37 *vs* 12/39, $P = 0.041$).

In the rhombic configuration group, two patients had screw exit, of which one experienced femoral neck non-union and underwent hip arthroplasty 14 months after surgery; the other patient had avascular necrosis of the femoral head after fracture union and underwent total hip replacement 25 months after surgery. Also, one case developed

TABLE 4 Clinical outcomes and complications comparison

Variables	Inverted triangle group (n = 51)	Rhombic group (n = 40)	Statistical value	P value
Harris hip score (mean ± SD)	80.67 ± 6.12	83.00 ± 6.27	t = −1.786	0.078[a]
Fracture union time (mean ± SD, weeks)	14.47 ± 1.29	13.45 ± 1.79	t = 3.154	0.002[a]
VAS score (mean ± SD)				
1 month	5.16 ± 1.75	3.53 ± 1.65	Z = −4.224	<0.001[b]
3 months	2.86 ± 1.77	1.93 ± 1.16	Z = −2.566	0.010[b]
6 months	1.45 ± 0.99	1.10 ± 0.81	Z = −1.779	0.075[b]
Complications				
Infection	0	0	-	-
Cortical perforation	0	0	-	-
Screw exit	5	2	-	0.460[c]
Cut-out	2	0	-	0.502[c]
Nonunion	4	1	-	0.380[c]
Avascular necrosis	4	2	-	0.691[c]

Abbreviation: VAS, visual analogue scale.; [a] Student t-test.; [b] Mann–Whitney U-test.; [c] Fisher's exact test.

necrosis of femoral head at 18 months after operation and did not agree to revision surgery.

In the inverted triangle configuration group, four patients experienced nonunion and one of them was associated with screw cut-out; of which, two cases underwent hip arthroplasty at 13 months postoperatively. Another two cases eventually developed femoral head necrosis and both of them received hip arthroplasty within 24 months after operation. In addition, two patients had femoral head necrosis after the fracture healed and had not undergone arthroplasty until the final follow-up. Another five patients experienced screw exit and one patient experienced screw cut-out 6 months after operation; of these, four patients received screw removal at 13 months postoperatively due to the hip pain. Wound infections and cortical perforation of screws were not observed in either group (Table 4).

Discussion

Despite the fact that optimal treatment for nondisplaced femoral neck fractures in elderly patients is controversial, internal fixation is the wildly used method in orthopedics, especially the cannulated screw system with inverted triangle configuration[6,27]. However, several studies have reported the unsatisfactory clinical outcomes due to nonunion, internal fixation failure, and femoral head osteonecrosis[24,28]. In this study, we compared the effectiveness of four screws in rhombic configuration and three screws in inverted triangle configuration to fix the nondisplaced femoral neck fractures in elderly patients. The result of our study indicated that four-screw fixation in rhombic configuration was superior to three-screw fixation in inverted triangle configuration in elderly patients with nondisplaced femoral neck fractures.

Harris Hip Score and Postoperative Pain

Compared with other types of internal fixation, the holding capability of cannulated screws was weaker, especially in elderly patients with poor bone quality.[29] As a result, many surgeons hoped to change the numbers and configuration of cannulated screws to improve the clinical outcomes and reduce the complications. Filipov introduced a method of biplane double-supported screw fixation and stated that this method could obtain reliable fixation and early rehabilitation in patients with osteoporotic femoral neck fractures[17]. However, it is a technical requirement for less experienced surgeons to insert the distal screw under the level of the small trochanter. Satish *et al.* used four quadrant parallel peripheral screws to fix elderly femoral neck factures and reported good radiological and clinical outcomes[30]. However, the effectiveness of this technique was doubted by other authors[31,32]. In our study, we used four screws in rhombic configuration to treat the nondisplaced femoral neck fractures in elderly patients and obtained a good hip function with an average Harris hip score of 83.00 at the final follow-up. Although the rhombic configuration could increase contact with bone and provide a better initial stability, the Harris hip score was not significantly improved compared with that of inverted triangle configuration at more than 2 years follow-up. Therefore, if only the final Harris hip score is considered, both rhombic and inverted triangle configuration can be used for nondisplaced femoral neck fracture fixation in elderly patients. However, patients in the rhombic configuration group had shorter fracture union time compared with those in inverted triangle configuration group, suggesting that rhombic configuration could make the patients earlier full weight-bearing. Besides, the VAS score of patients in rhombic configuration group was lower than that of inverted triangle configuration group in the first month and third month after surgery, but no significant difference was found at the sixth month after the operation. This indicated that patients fixed with rhombic configuration had a better early postsurgical experience with less operational pain than that of inverted triangle configuration fixation.

Intraoperative Outcomes and Hospital Stays

The rhombic configuration would cost extra time to insert the fourth screw, which will inevitably increase the fluoroscopy time and blood loss. Although there was a statistical difference in blood loss, operative time, and incision size between the two groups, we believed that these small differences (12 mL, 12 min, 1.3 cm) would not have a significant impact on clinical outcomes. Meanwhile, with the increase of proficiency in surgical skills, the difference in fluoroscopy and operative time will diminish gradually. Interestingly, the rhombic configuration group has shorter hospital stays compared with the inverted triangle configuration group. Although the reasons require further investigation, we think it could be partially explained by the fact that four-screw fixation with rhombic configuration make treating surgeons more confident due to its increased stability[22,33].

Complications

It has been reported that the complication rate after cannulated screw fixation of nondisplaced femoral neck fracturs ranged from 8.9% to 31.8% and the overall complication rate (15/91, 16.48%) of our study was consistent with the ones reported in other studies[14,16].

In our study, patients in the rhombic configuration group tended to be complicated with lower rate of internal fixation failure (5% *vs* 13.73%) and nonunion (2.5% *vs* 7.84%). Anatomical reduction and rigid fixation are essential for treatment of femoral neck fractures. Yang *et al.* reported that the screw configurations, displacement of the fracture, and reduction quality affected the nonunion of femoral neck fractures[34]. Due to no or minimal displacement of the fracture in our patients, the configuration of screws was particularly important for the occurrence of complications. In elderly patients with poor bone quality, there are two potential risks for three screws fixing femoral neck fractures, including inadequacy of fixation and inability to control collapse[30]. While four-screw fixation with rhombic configuration could provide excellent initial stability for the femoral neck fracture. According to the mechanical study of Benterud *et al.*[35], the trabeculae in the superior and central of the femoral head was denser than that in the inferior portion. Therefore, adding a fourth screw in this area could provide more support and had greater pullout strength. Besides, in a biomechanical study which compared different configurations of cannulated screws for femoral neck fractures with finite element analysis, Ren *et al.*[33] found rhombic configuration may result in better anti-shearing force and dispersion of stresses compared with inverted triangle configuration. Some authors worried about that removing more bone in the rhombic configuration could result in higher rate of nonunion.[22] However, our result (1/40 *vs* 4/51, $P = 0.380$) indicated that such worry was not necessary. In short, we believe that adequate stability could be obtained through four-screw fixation in rhombic configuration which could lead to a lower rate of fracture nonunion.

Several studies reported cortical perforation when rhombic configuration was used to fix femoral neck fractures and attributed it to the limited space of femoral neck[20,22]. In our study, no case in either group had cortical perforation. By radiological measurement, Pathrot *et al.* found the width of femoral neck in Indian population was 32.55 ± 3.14 mm[36]. Subtracting approximately 2 mm of cortical thickness, there was sufficient space (28.55 mm) for four cannulated screws of 7.0 mm diameter in rhombic configuration to be placed in the femoral neck[36]. In addition, there was no significant difference in avascular necrosis of femoral head between the two groups (2/40 *vs* 4/51, $P = 0.691$), which indicated that adding a fourth screw would not increase the risk of femoral head necrosis. Moreover, compared with inverted triangle configuration, the rhombic configuration only added a proximal cannulated screw. The manipulation was relatively simple and learning curve was short. Taken together, four-screw fixation of femoral neck fractures in rhombic configuration had the advantages of reducing the failure rate of internal fixation without increasing the risk of femoral head necrosis through a simple procedure.

Strengths and Limitations

To our knowledge, the current study was the first study to compare the clinical outcomes and postoperative complications of nondisplaced femoral neck fractures fixed with two different configurations of cannulated screws in elderly patients. Despite this, there are several potential limitations in our study that should be mentioned. First, the retrospective design has inherent limitation in data collection and accuracy. Second, the relatively small number of cases may result in an underestimation of the true complication rate. Third, several surgeons with different experience performed the fixation operations, which could cause a potential bias influencing the final operational outcomes. Hence, more prospective studies with large sample size, randomized and double-blinded design are needed to confirm our findings.

Conclusions

In conclusion, four-screw fixation in rhombic configuration was superior to three-screw fixation in inverted triangle configuration in the treatment of nondisplaced femoral neck fractures in elderly patients due to less early postsurgical pain, shorter fracture union time, lower complication rates, and thus we suggest that four-screw fixation in rhombic configuration should be considered for the elderly patients with nondisplaced femoral neck fractures.

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Data Availability Statement

The data contributing to this article are available from the first author upon reasonable request.

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