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Evaluation of full thread screw and different fixation configurations in Pauwels type III femoral neck fracture

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A R T I C L E I N F O

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A B S T R A C T

Objectives: The purpose of this study is to evaluate the value of full thread screw and different fixation configurations in Pauwels type III femoral neck fracture.
Methods: A total of 40 artificial femoral model specimens were chosen, and Pauwels type III femoral neck fracture was simulated upon osteotomy at 80°. According to random number table, models were divided into four groups (10 cases in each group): Group A received the paralleled fixation with three partial thread screws (PTSs), group B received the crossed fixation with three PTSs, group C received the paralleled fixation with two full thread screws (FTSs) and one PTS, and group D received the crossed fixation with two FTSs and one PTS. Changes including the model rigidity, axial displacement in fatigue test and limit loads for Pauwels type III femoral neck fracture models were analyzed through MTS 858 Mini Bionix II test system.
Results: Among four groups, the model rigidity, axial displacement in fatigue test and limit loads were the highest in group D, and they were the lowest in group A. However, the model rigidity, axial displacement in fatigue test and limit loads between group B and group C showed no statistically significant difference ($P > 0.05$). Eventually, all the specimens were displaced along the fracture lines while the femoral head was split at varying degrees. After splits, the removal rate of fixation screws in group A (60.0 %) and group C (40.0 %) was significantly higher than that of group B (10.0 %) and group D (0 %) ($P < 0.05$), but it showed no statistically significant difference between group A and group C, and between group B and group D ($P > 0.05$).
Conclusions: The crossed fixation configuration with two FTSs and one PTS in group D is proven to be more effective, which can go against the shear stress, tension and introversion in Pauwels type III femoral neck fracture models.

1. Introduction

Femoral neck fracture is one of the most common types of fracture in clinical diagnosis [1]. Pauwels classification is one of the most commonly used classification methods for femoral neck fractures in clinical practice [2,3]. Scholars considered that femoral neck fracture can be mechanically analyzed through Pauwels classifications that are mainly based on the included angle between bone

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fracture line and horizontal plane; if the angle exceeds 50°, Pauwels type III femoral neck fracture will be confirmed in clinical application [4,5]. Patients of Pauwels type III femoral neck fracture have to bear quite high shear stress and tension. The majority of patients are prone to have failure of internal fixation and re-displacement which can produce an obvious impact on the bone healing conditions and be bad for the fast rehabilitation [6]. Therefore, how to treat Pauwels type III femoral neck fracture has always been a thorny problem in clinical research. Cannulated screws have been mostly applied for internal fixation in treating bone fracture patients, and paralleled fixation with an inverted triad of three partial thread screws (PTSs) has been recommended [7]. With the further clinical research and fixation configurations improvements in recent years, some scholars have focused on the advantages of internal fixation configurations with full thread screw (FTS) [8]. In terms of mechanical property, better fixation effects can be achieved if one screw is vertically compressed on the bone fracture line [9]. In this study, the artificial femoral model specimens have been used for stimulation of Pauwels type III femoral neck fracture. Through the different configurations and fixation screws, changes such as the model rigidity, axial displacement in fatigue test and limit loads for the model specimens of Pauwels type III femoral neck fracture were observed, for further providing theory basis on clinical treatment of Pauwels type III femoral neck fracture.

2. Materials and methods

This study was approved by The Ethics Committee of Putuo Hospital Affiliated to Shanghai University of Traditional Chinese Medicine, China. Participants have provided their written informed consent to participate in this study.

2.1. *Femoral neck fracture modeling*

Synbone proximal femoral bone model (2220 Femur Proximal) were chosen as research specimens, including stimulation structures of cortical bone and cancellous bone. A total of 40 specimens of Pauwels type III femoral neck fracture (Fig. 1) were simulated upon osteotomy at 80°. Bone fracture line was extended from femoral head to femoral neck base. Two pins were marked on the top and down sides. The position and angle of bone fracture line was confirmed through frontal X-ray films (Fig. 2).

Internal fixation modes included 4 groups (Fig. 3): Group A received the paralleled fixation with three PTSs in an inverted triad way. Screws were paralleled to each other and parallel to long axis of femoral neck. In the downward direction, one screw was placed besides thigh bone, and its entry depth exceeded the horizontal level of lesser trochanter. The anterior superior and posterior superior screws should be close to the anterior femoral neck and posterior cortex. Screw heads were located below 5–10 mm of femoral head articular surface. Group B received the crossed fixation with three PTSs. According to frontal X-ray films, one screw was vertical to bone fracture line and below the fracture ends; the remaining two paralleled screws were crossed at the distal end of fracture line. Lateral X-ray films indicated that three screws were paralleled with each other. The entry depth of two paralleled screws exceeded the horizontal level of lesser trochanter, which should be close to the anterior femoral neck and posterior cortex. Screw heads were located below 5–10 mm of femoral head articular surface. Group C received the paralleled fixation with two FTSs and one PTS, and its fixation configurations were just the same as group A; there something different was that the anterior superior and posterior superior PTSs were replaced with FTSs. Group D received the crossed fixation with two FTSs and one PTS, which its fixation configurations were just the same as group B; what's the difference was that two paralleled PTSs were replaced with FTSs.

2.2. *Biomechanical test methods*

Biomechanical indicators of the specimens including model rigidity, axial displacement in the fatigue test and limit loads were used to analyze the screw removal conditions after destruction. The properties of biochemical indicators in the model specimens were

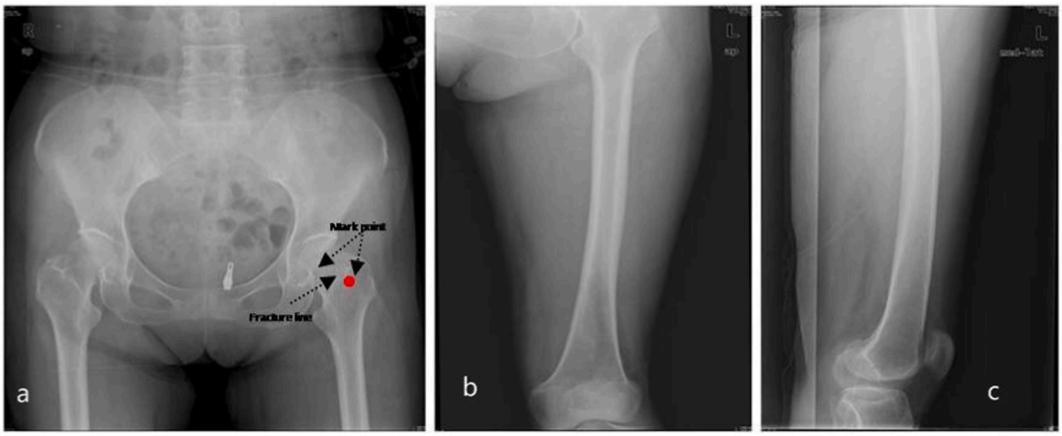

Fig. 1. Pauwels type III femoral neck fracture model. (a) Two pins were marked on the top and down sides, and (b,c) Pauwels type III femoral neck fracture.

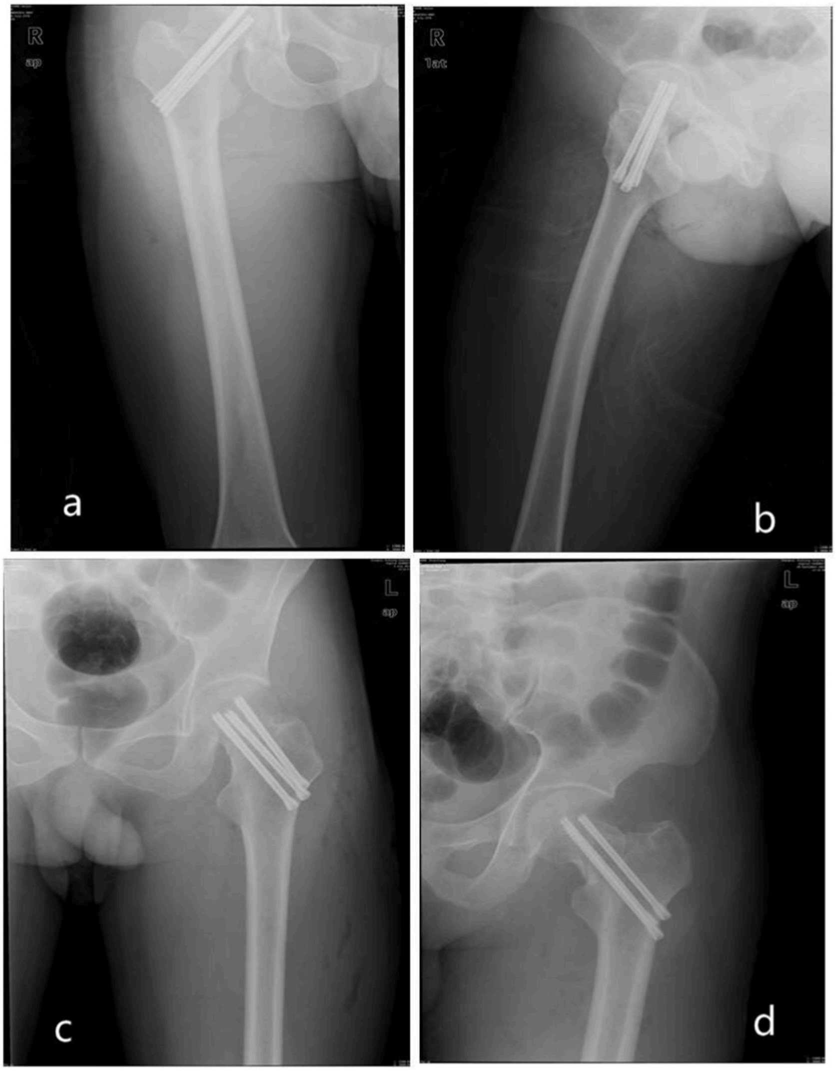

Fig. 2. X-ray film analysis for four model specimens. (a,b) FNF treated with two FTSs and one inferior PTSs, and (c,d) FNF treated with three parallel FTSs.

analyzed through MTS 858 Mini Bionix II test system (MTS Systems Ltd., Eden Prairie, MN, USA). Among four groups, the coronal planes of these specimens were fixed in 25° adduction and vertical plane in neural position. In the trials, axial loads were vertically downward to stimulate the hip joint stress while standing on one leg. The loads on the femoral head were achieved through connecting the test system with experimental prototypes of acetabulum. The horizontal prototype and arc-shaped prototype could be further classified. The horizontal prototype could apply the axial loads along the femur while the arc-shaped prototype could apply the axial loads. Based on the stimulation of acetabulum, the frictional force between femur head and contact surface might be enhanced. Through ±16° rotation of arc-shaped prototype, the looped torsion loads might be added. MTS extensometer (Model 634.25F-24 Axial Extensometer) was used for the measurement of displacements. Both ends of the extensometer were fixed on the proximal and distal bone fracture line through Kirschner wire, and its entry points were consistent for all the specimens and the gauge was parallel to bone fracture line. In the trial, the descending distance of the machine head could be automatically recorded of which could also be known as axial displacement of bone fracture. The experimental equipment was provided in Fig. 4.

2.3. Graded exercise testing

On the model specimens, the loads were graded from 100 N at 2 N/min to 1500 N; horizontal prototype was applied at the acetabulum side. According to axial displacement of bone fracture, load-displacement curve was drawn out (Fig. 5). The limit loads of the specimens would be known since the fixation was failed below 1500 N. Failed fixation referred that femoral head was displaced for more than 5 mm along the bone fracture line and the screw was transformed or went through femoral head.

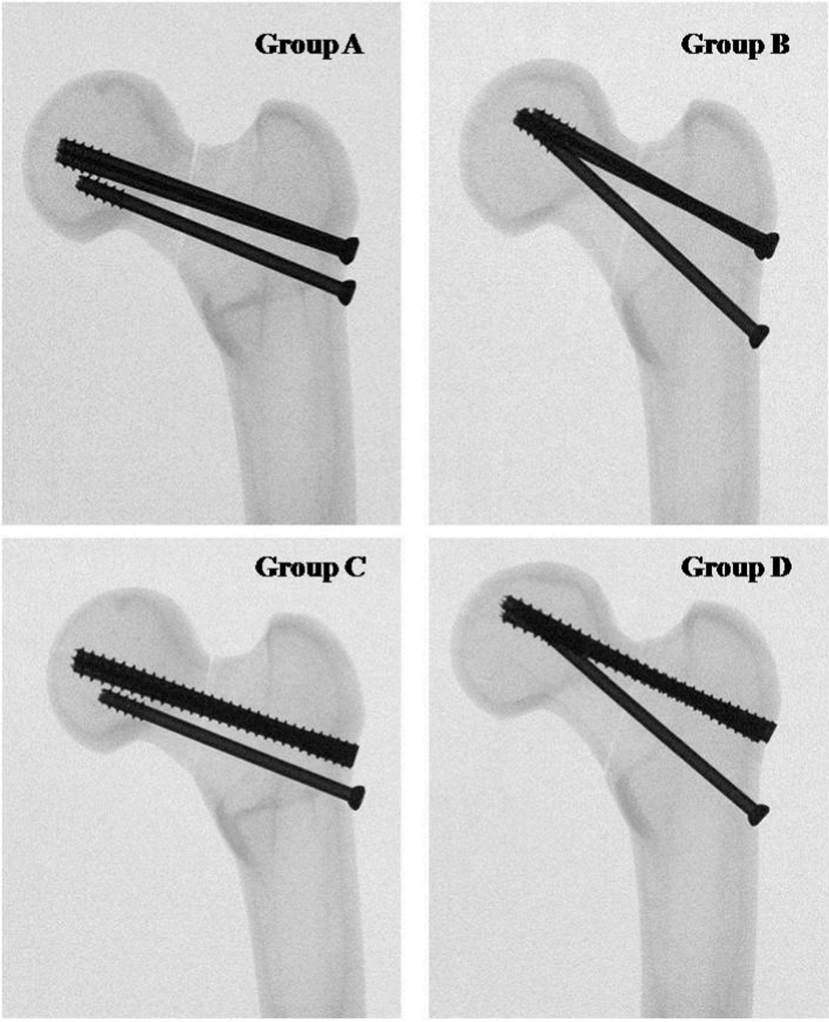

Fig. 3. Screw configurations in four model specimens. Group A received the paralleled fixation with three PTSs in an inverted triad way, group B received the crossed fixation with three PTSs, group C received the paralleled fixation with two FTSs and one PTS, and its fixation configurations were just the same as group A; group D received the crossed fixation with two FTSs and one PTS, which its fixation configurations were just the same as group B.

2.4. Fatigue test

A total of 3 Hz of loads were added on the model specimens for 10,000 times. Arc-shaped prototype was applied at the acetabulum side. The load patterns included axial load and torsion load. In a cycle, axial load changed from 500 N to 0 N in the sine way and then turned back to 500 N in the same way. Torsion loads were added since the experimental prototype of the acetabulum was rotated at $\pm 16^{\circ}$. In a cycle, the experimental prototype of the acetabulum took the vertical movement distance at 1 mm. For each cycle, the maximal axial displacement was seen as axial displacement of bone fracture. If a specimen was failed, the number of cycles might be recorded.

2.5. Stressing test

The loads were added on the model specimens at 2 mm/min until the bone fracture was visibly observed or the load-displacement curve reached its ultimate strength.

2.6. Statistical processing

Statistical Product Service Solutions (SPSS) version 18.0 software (SPSS Inc., Chicago, IL, USA) was used in the experiments; measurement data was expressed by $\overline{\chi} \pm s$, and verified by *t*-test. Enumeration data was expressed by percentage and verified by χ^2 test.

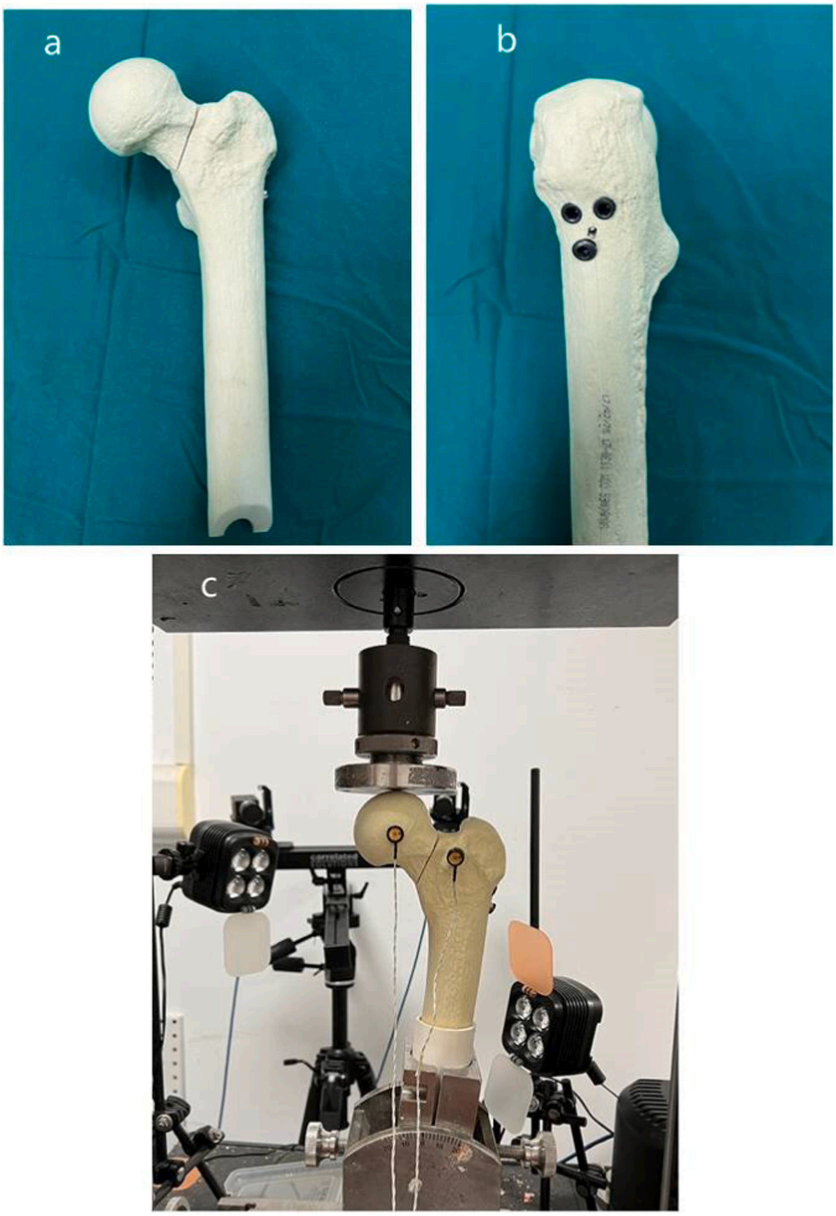

Fig. 4. Experimental process diagram. Model rigidity, axial displacement in the fatigue test and limit loads were analyzed through MTS 858 Mini Bionix II test system. (a,b): the specimen was fixed with the inverted triangle construct method, and (c): the position of specimen simulating standing.

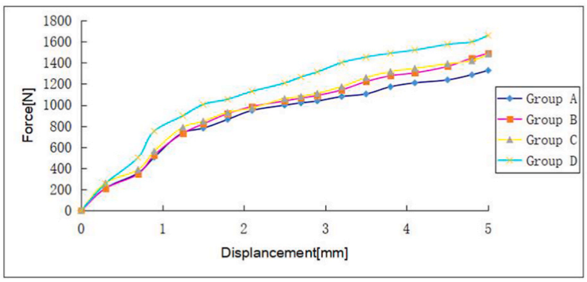

Fig. 5. Load-displacement curve for four model specimens. On the model specimens, the loads were graded from 100 N at 2 N/min to 1500 N.

Analysis of variance was applied for group contrasts and tested by *F* value; P < 0.05 indicated that there was statistically significant difference.

3. Results

3.1. General data

A total of 40 artificial femoral model specimens were investigated while Pauwels type III femoral neck fracture was simulated upon osteotomy at 80°. According to random number table, models were divided into four groups, 10 cases in each group. Six left model specimens and 4 right model specimens were included in group A, 5 left model specimens and 5 right model specimens in group B, 5 left model specimens and 5 right model specimens in group C, and 4 left model specimens and 6 right model specimens in group D. The proportion of left and right model specimens among four groups was not significantly different ($P > 0.05$).

3.2. Biomechanical indicators for four model specimens

Biomechanical indicators including model rigidity, axial displacement in fatigue test and limit loads for four model specimens were shown in Table 1. It was suggested that the model rigidity, axial displacement in fatigue test and limit loads in group D were significantly higher than those in the other three groups (P < 0.05). The model rigidity, axial displacement and limit loads were the lowest in group A among four groups (P < 0.05). Furthermore, the model rigidity, axial displacement in fatigue test and limit loads between group B and group C showed no statistically significant difference (P > 0.05).

3.3. Failure model effectiveness analysis for four model specimens

All the specimens were displaced along the fracture line while the femoral head was split at varying degrees, and the screw removal rate was measured. As shown in Table 2, after destruction, the removal rate of fixation screws in group A (60.0 %) and group C (40.0 %) was significantly higher than that of group B (10.0 %) and group D (0 %) ($P < 0.05$); the removal rate of fixation screws between group A and group C, between group B and group D showed no statistically significant difference ($P > 0.05$).

4. Discussion

In clinical practice, femoral neck fracture mainly accounts for 50%–60 % of hip fracture events and occurs in a direct and indirect manner. The direct causes include high-altitude failing, and impact of external forces, and indirect causes include rotating force of lower limbs. The elderly are mainly suffering from low-energy failing and osteoporosis, and the young people are prone to high-energy torsion and violence. In clinical treatment, Pauwels type III femoral neck fracture can be cured using different treatment strategies [10–14]. In this paper, the artificial model specimens for Pauwels type III femoral neck fracture were investigated and found that the crossed fixation configurations with two FTSs and one PTS are effective to treat Pauwels type III femoral neck fracture.

Multiple cannulated cancellous screws are used widely for treating with femoral neck fracture due to its advantages such as less tissue invasion, less blood loss, and shorter operation time [15,16]. Moreover, the configuration of three parallel PTSs can be utilized to compress the fracture fragments and eliminate a potential fracture gap which can enhance fracture healing [17,18]. Previously, the paralleled fixation with three PTSs in an inverted triad way has been widely recommended. This is because that three PTSs accord with dynamic compression principle so that the loads produced by hip joint muscle construction can be applied on the bone fracture sites and promote the bone healing [19]. In addition, three PTSs are basically parallel to long axis of femoral neck and may be removed upon absorption, which produce no impacts on the connection between femoral head and neck. The compression of bone fracture site may reduce the loads applied by internal fixation and increase the possibility of early weight training [20]. With the constant medical development, it is considered that the conventional inverted triad partial thread cannulated screws have its medical limitations for treatment of Pauwels type III femoral neck fracture, because its sliding compression directions are not vertical to bone fracture line. As a result, the compression on the bone fracture site may also increase the shear stress [21]. Some investigations proved that the crossed screws may be applied for internal fixation of Pauwels type III femoral neck fracture [22]. Based on mechanical property of the crossed screws, the compressed screws that are vertical to bone fracture line can generate a direct compression on the bone fracture site, go

Table 1
Biomechanical indicators for four model specimens.

Groups	n	Rigidity (N/mm)	Axial displacement in fatigue test (mm)	Limit loads (N)
Group A	10	254.33 ± 16.78	0.21 ± 0.06	1348.72 ± 144.38
Group B	10	272.52 ± 20.05[a]	0.29 ± 0.08[a]	1489.43 ± 182.96[a]
Group C	10	271.34 ± 19.86[a]	0.28 ± 0.05[a]	1482.64 ± 181.47[a]
Group D	10	306.25 ± 24.72[abc]	0.36 ± 0.09[abc]	1658.29 ± 218.65[abc]
F	–	11.20	7.31	4.76
P	–	P < 0.05	P < 0.05	P < 0.05

Notes: comparison with group A, [a]$P < 0.05$; comparison with group B, [b]$P < 0.05$; comparison with group C, [c]$P < 0.05$.

Table 2
Failure model effectiveness analysis for four model specimens (case load).

Groups	n	Screw removal rate (%)
Group A	10	6 (60.0)
Group B	10	1 (10.0) [ac]
Group C	10	4 (40.0)
Group D	10	0 (0) [ac]
χ^2	–	11.411
P	–	$P < 0.05$

against the tension on the bone fracture site and prevent the introversion of bone fracture. Through the compression, the shear stress on the bone fracture site may be obviously offset with the increased frictional force on the bone fracture site and supporting forces of the screws [23]. Therefore, the crossed screws become the hot topics in the current research. With respect of screw types, some scholars provided the evidence that FTS can fill a gap for the insufficient tension of PTS, which can promote the rehabilitation of collodiaphysial angle and front inclination angle. In view of the unstable essence of the displaced femoral neck fracture with comminuted posteromedial cortex, the traditional configuration of three parallel compression screws is consistently under debate. On the premise of less invasive, FTS has been recommended for internal fixation [17,24]. However, how to treat Pauwels type III femoral neck fracture has always been a controversial topic in clinical studies.

Biomechanical changes based on the fixation modes with different screw types were observed in this study and indicated that the crossed fixation with two FTSs and one PTS can improve the model rigidity, axial displacement and limit loads, indicating the better fixation effects for treatment of Pauwels type III femoral neck fracture. This is because that one screw that is vertical to bone fracture line can produce a vertical compression on the bone fracture site and achieve the highest bone healing effects. In addition, two paralleled screw configurations are just like the conventional parallel screw fixations, which conform to the compression principles and promote the bone healing [25]. In this study, two PTSs were replaced with two FTSs since FTS has better internal fixation effects due to the increases of occlusal forces [26,27]. Since the model specimens can not stimulate the bone healing procedures in the human body, all the specimens undertook the destruction tests to stimulate the early failure conditions. Results showed that the screw removal rate in group B and group D is significantly lower than that of group A and group C. Compared with paralleled fixation configurations, the crossed fixation configurations can further prevent the removal of thread screws. That is to say that the crossed configurations have better control effects of introversion for treatment of Pauwels type III femoral neck fracture in comparison with paralleled configurations. No significant differences between group A and group C are observed. The removal rate in group C is slightly lower since FTS has higher resistance and is hard to be removed.

There are still limitations in this study. First, the relatively small number of model specimens may result in an underestimation of the true results. Second, this study is unable to test the long-term results of healing and their effect on the rotational stability provided by the fixation configurations. Third, our experiment is intended as an artificial model specimens with incorporated screws for Pauwels type III femoral neck fracture. Therefore, future work would do well to investigate other planes of motion and performance in a cadaveric model.

5. Conclusions

To sum up, the crossed fixation configurations with two FTS and one PTS are clinically proven to be more effective to go against the shear stress, tension and introversion on the treatment of Pauwels type III femoral neck fracture.

Funding

None.

Ethical approval

This study was approved by The Ethics Committee of Putuo Hospital Affiliated to Shanghai University of Traditional Chinese Medicine, China, No. PTEC-R-2022-40(Y)-1.

CRediT authorship contribution statement

Jianjun Qiu: Conceptualization. **Hanlin Zou:** Conceptualization. **Lei Zhang:** Conceptualization. **Xu Zhou:** 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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