Int J Clin Exp Med 2019;12(7):9251-9258
www.ijcem.com /ISSN:1940-5901/IJCEM0092808

Original Article

Biomechanical study of reduction quality and effects of the medial wall on intertrochanteric fractures based on the new AO classification

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Received February 20, 2019; Accepted June 5, 2019; Epub July 15, 2019; Published July 30, 2019

Abstract: Objective: Aiming to provide biomechanical support for clinical operations and verify the influence of the medial wall on the stability of fractures, intertrochanteric fractures with different reduction quality levels and conditions were established. Biomechanical analysis was also conducted. Methods: Artificial bones (Synbone) were used to simulate AO31A1 and A2 fractures. The models were divided into four groups. Group A was A1 fractures with an intact medial wall. Group B was A2 fractures lacking an anteromedial wall. Group C was A2 fractures lacking a posteromedial wall. Group D was A2 fractures featuring the loss of the medial wall. Reduction quality contained anatomic reduction, negative, and positive support models. Vertical compression testing was carried out and the load was recorded. Results: In group A, the extreme load of positive support was 913.35 ± 72.26 N, higher than that of anatomic support (802.79 ± 70.64) N ($P < 0.05$). The extreme load of anatomic support 802.79±70.64 N was higher than that of the negative support (676.29 ± 67.48) N ($P < 0.05$). In group B, the extreme load of positive support (924.27 ± 37.45) N was higher than that of anatomic support (896.10 ± 107.89) N and negative support (801.11 ± 28.72) N. There were significantly statistical differences between the positive support model and negative support model ($P < 0.05$). In group C, the extreme load of anatomic reduction (984.22 ± 12.63) N was greater than that of positive support (936.95 ± 16.78) N and negative support (918.04 ± 28.86) N ($P < 0.05$). However, there were no statistical differences between the negative support model and positive support model ($P > 0.05$). The extreme load of anatomic reduction in group A was higher than that in group D ($P > 0.05$). Conclusion: For AO31A1 and A2 intertrochanteric fractures, biomechanical stabilities of the positive support and anatomic reduction were better than those of the negative support. If PFNA-II was used to treat intertrochanteric fractures, the loss of the medial wall would have no effect on the stability of the fracture.

Keywords: Intertrochanteric fracture, positive cortical support, negative cortical support, medial wall, biomechanics, reduction quality

Introduction

Femoral intertrochanteric fractures are common among elderly people, accounting for about 50% of hip fractures. Incidence rates have increased recently with the aging of the society [1, 2]. Surgical operations are still the first choice for treatment of intertrochanteric fractures. In 1980, bone quality, fracture type, reduction quality, design of the implant, and position of the implant were noted as five major factors related to surgical outcomes, as described by Kaufer [3]. Therefore, the stability of fractures may depend on the quality of fracture reduction after internal fixation. Fractures are expected to be reduced anatomically. However, it is difficult to achieve this reduction due to many factors, such as the complex anatomic structure. Since most elderly patients have various medical conditions, to reduce extra operation times and incidence of surgical accidents, repeated reduction should be avoided during surgery. Chang SM [4] has defined the positive cortical support as the medial cortex of the head-neck fragment displaced and located a little bit super-medially to the medial cortex of the femur shaft in the AP view, as well as the negative cortical support as the opposite of this

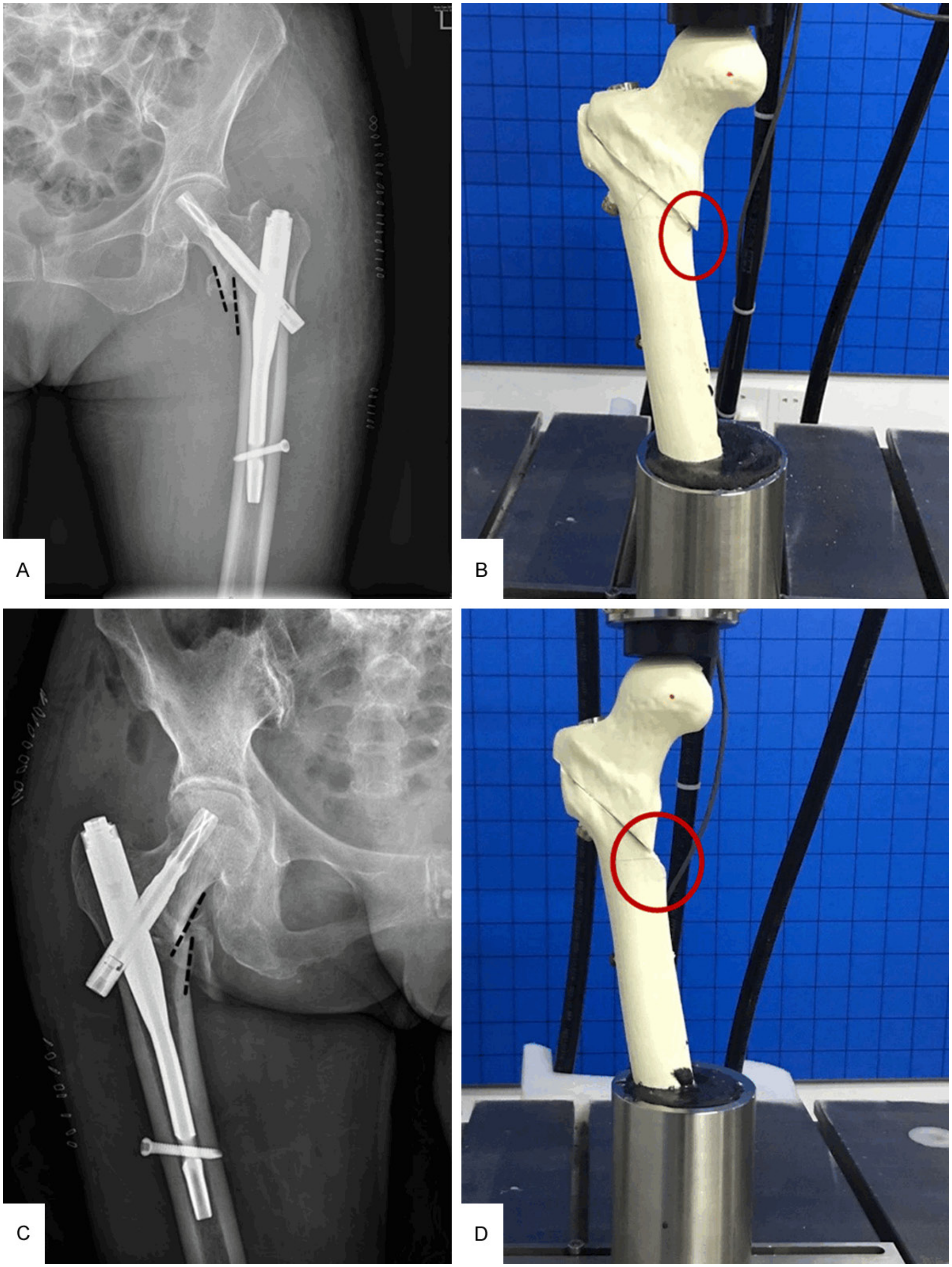

Figure 1. Positive support and negative support: The positive support as the medial cortex of the head-neck fragment displaced and located a little bit super-medially to the medial cortex of the femur shaft in AP view (A, B) and the negative cortical support as the opposite of this situation with no cortical buttress (C, D). (A, C) X-ray; (B, D) Testing specimens.

situation with no cortical buttress (**Figure 1**). It was also found that patients in the positive cortical support group had the least loss in neck-shaft angle and neck length. They began ground-walking much earlier than the negative reduction group, with good functional outcomes and less hip-thigh pain presence. However, there have been few relevant biomechanical support studies.

A new proximal femoral fractures classification has been published by the AO/ASIF foundation in 2018. It emphasized the lateral wall and weakened medial wall. The importance of the lateral wall of the proximal femur has attracted more and more attention in recent years [5]. In the past, it was the medial wall that was considered to play an important role in the stability of intertrochanteric fractures. Therefore, there remains a controversy concerning the importance of the medial wall or the lateral wall.

According to biomechanical testing conducted in the current study, the stabilities of AO31A1 and A2 fractures fixed by different reduction qualities and the importance of the medial wall were investigated (**Figure 2**).

Materials and methods

Synthetic proximal femur bones (Synbone, Model: LD2220.01, direction: right side, neck stem angle: 135°, medullary cavity diameter: 12 mm, and femoral head diameter: 48 mm) were used. The length from the top of the trochanter to the distal condyle was 337 mm. The T score was -3.0, simulating a severely osteoporotic bone [6].

PFNA II (the creation, main nail length: 170 mm, diameter: 9 mm, titanium alloys) was used to fix the fractures.

Preparation of fracture models

According to the new AO classification of 31A1 and A2 fracture models of intertrochanteric fractures, the fracture models were simulated.

The horizontal line was made 3 cm below the innominate tubercle of the greater trochanter. At the intersection between this horizontal line and the lateral cortex, a 45-degree angle line was made and a 2 cm distance was taken away from the intersection along the ray. The end point of the line was defined as d. Another horizontal line was made at the lowest point of the lesser trochanter and the intersection between this line. The anteromedial wall of the femur was defined as c. The AO31A1 fracture model was made by making a straight-line f across the two points of c/d (**Figure 3**). The AO31A2 fracture model was made by removing the anteromedial, posterior medial wall, or total medial wall of type A1 fracture model. All fracture models were completed by the same senior surgeon.

Experimental models

There were 24 fracture models, including 8 negative supports, 8 positive supports, and 8 anatomic reductions in groups A, B, and C. There were AO31A1 fracture models in group A, AO31A2 (anteromedial wall removal) in group B, and AO31A2 (posteromedial wall removal) in group C. In group D, 8 AO31A2 fracture models were made with the medial wall removed in the anatomic reduction. The PFNA-II was placed according to recommended techniques. The lag screw was in the middle and lower third of the femoral neck in the posteroanterior view, as well as in the middle of the femoral neck in the lateral view. The TAD was between 20 and 25 mm [7-9].

Biomechanical tests

The fracture models were loaded continuously under vertical compression. The position of the models was simulated with one leg standing. The coronal plane of the models was 25° adduction and the sagittal plane was neutral. The distal part of the specimen was clamped, then the model was placed on the base of a spine testing machine (SBM2000, Shanghai Sanyou Medical) (**Figure 4A**). Clamps and compression of the models were designed by present researchers. The vertical compression test was carried out. The motion tracking system (Optitrack Flex13, Natural Point Inc, Corvallis, Oregon, USA) was used to record data. In the vertical compression test, the indenter was pressed down at a 5 mm/min compression speed until the visible failure of internal fixation (screw blade cutting out, screw blade withdrawing, screw blade broken, or fracture reduction loss) or bone fracture occurred (**Figure 4B**).

Statistical analysis

SPSS 23.0 statistical software was used to analyze data. One-way ANOVA was used to

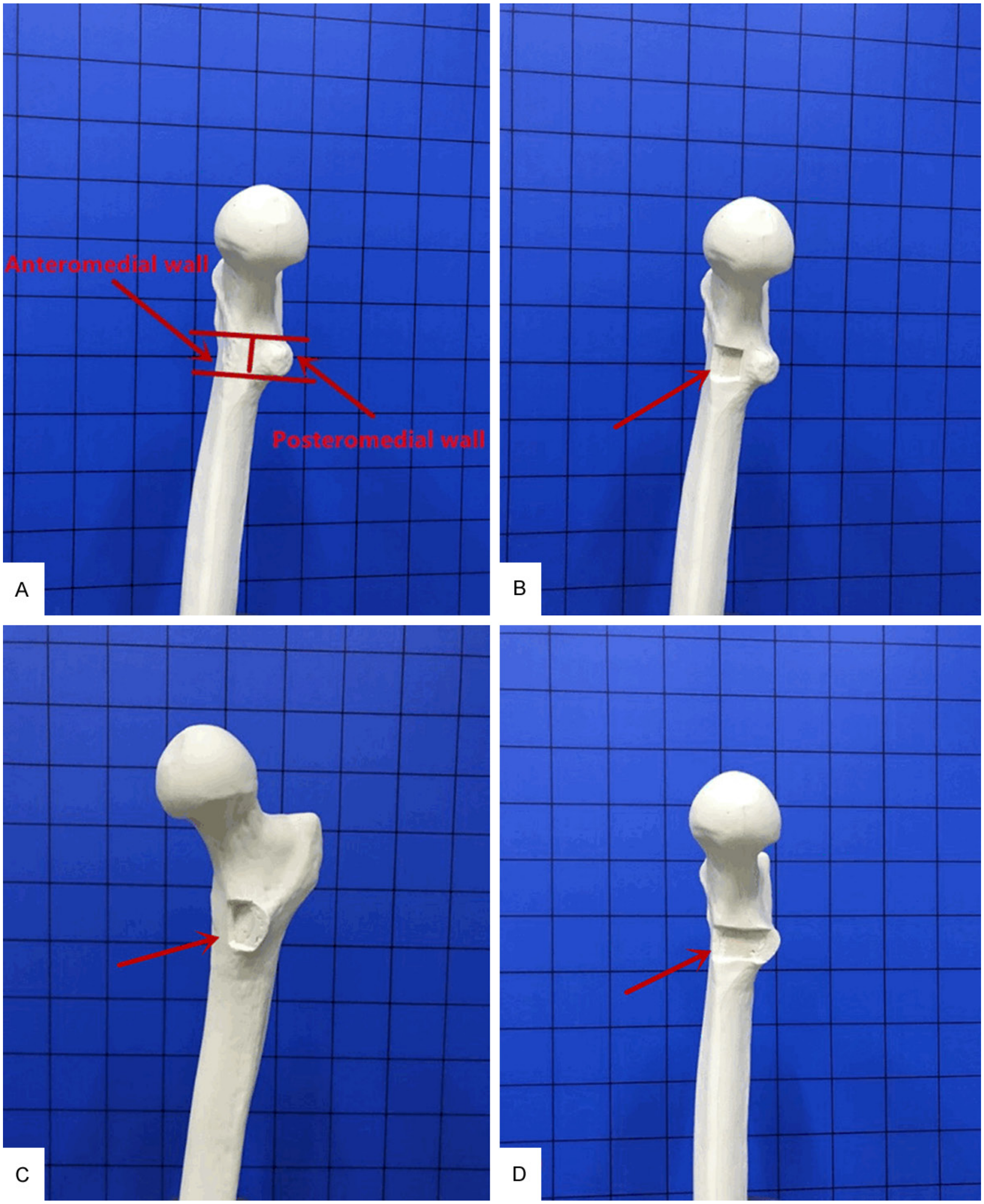

Figure 2. Different reduction qualities are as follows. The distinction between the anterior inner wall and posterior inner wall (A); Anteromedial wall removal (B); Posteromedial wall removal (C); Medial wall removal (D).

analyze comparisons between data of multiple groups. LSD tests were used to compare the data of two groups. Student's t-tests were used to analyze comparisons between the two groups. Differences are considered statistically significant when *P*-values < 0.05.

Results

Effects of the shape of the medial wall on stability

In Group A, the extreme load of positive support model was 913.35 ± 72.26 N, higher than

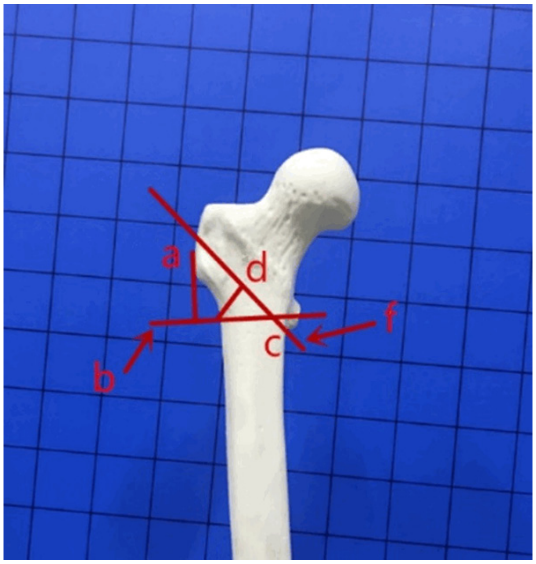

Figure 3. Schematic of the creation of intertrochanteric fractures (OTA 31-A1). a. Innominate Tubercle; b. Horizontal line; c. Intersection between the horizontal line that was made at the lowest point of the lesser trochanter and the anteromedial wall; d. The end-point of the 45-degree angle line; f. Sraight-line across the two points of d\c.

that of the anatomic reduction model ($P < 0.05$), as shown in **Figure 5**. Furthermore, the load of the anatomic reduction support model was 802.79 ± 70.64 N, higher than that of the negative support model (676.29 ± 67.48) N ($P < 0.05$).

In Group B, the extreme load of the positive support model was 924.27 ± 37.45, higher than that of the anatomic reduction model (896.10 ± 107.89) N ($P > 0.05$) and negative support model (801.11 ± 28.72) N ($P < 0.05$), as shown in **Figure 5**.

In Group C, the extreme load of the anatomic reduction model was 984.22 ± 12.63 N, greater than that of the positive support model (936.95 ± 16.78) N ($P < 0.05$) and negative support model (918.04 ± 28.86) N ($P < 0.05$), as shown in **Figure 5**. However, there were no differences between the negative support model and positive support model ($P > 0.05$) (**Figure 5**).

Influence of the medial wall on biomechanical stability

Compared with the anatomic reduction model, the load in group A was higher than that of group D ($P > 0.05$), as shown in **Figure 6**.

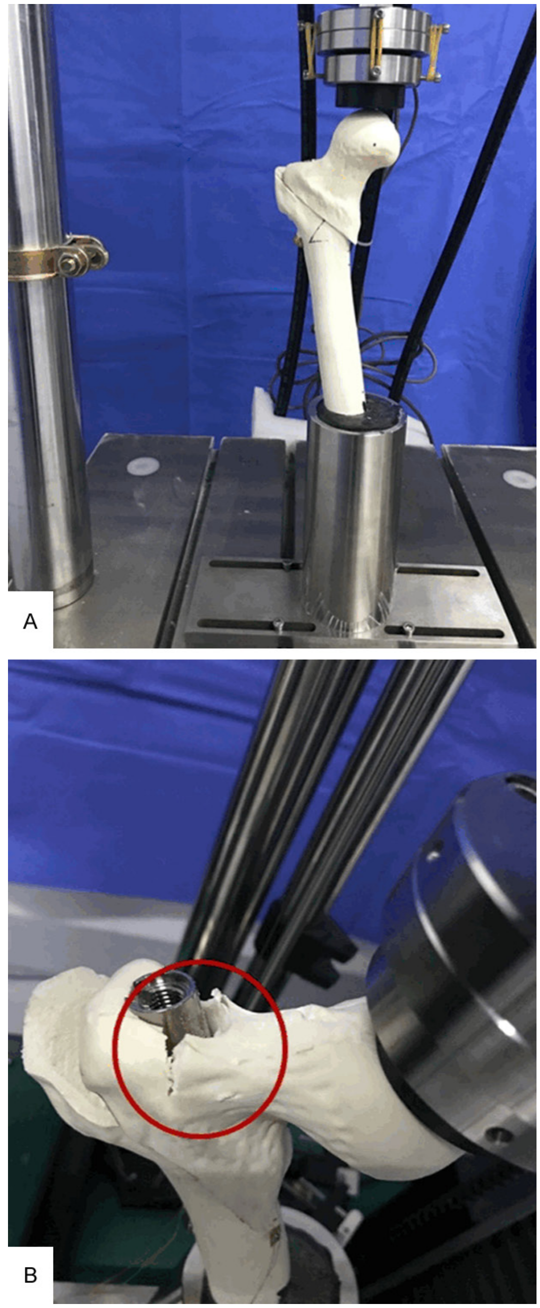

Figure 4. Biomechanical tests were conducted using a spine testing machine (A); Bone fracture (B).

Discussion

With the rapid development of an aging population in China, incidence rates of hip fractures in the elderly have increased recently. This has brought a huge burden to the society. To ensure a fast recovery and reduce complications, surgery is the first choice for intertrochanteric fractures. Intramedullary fixation has been accepted by more and more trauma surgeons [10, 11].

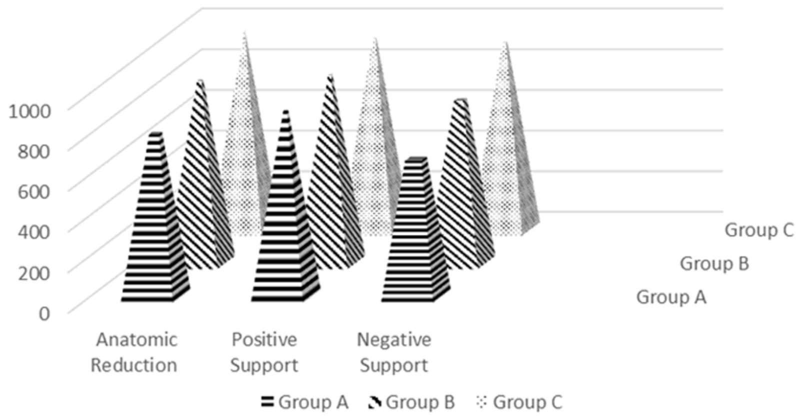

Figure 5. The extreme load of the positive support model, anatomic reduction model, and negative support model in Groups A, B, and C.

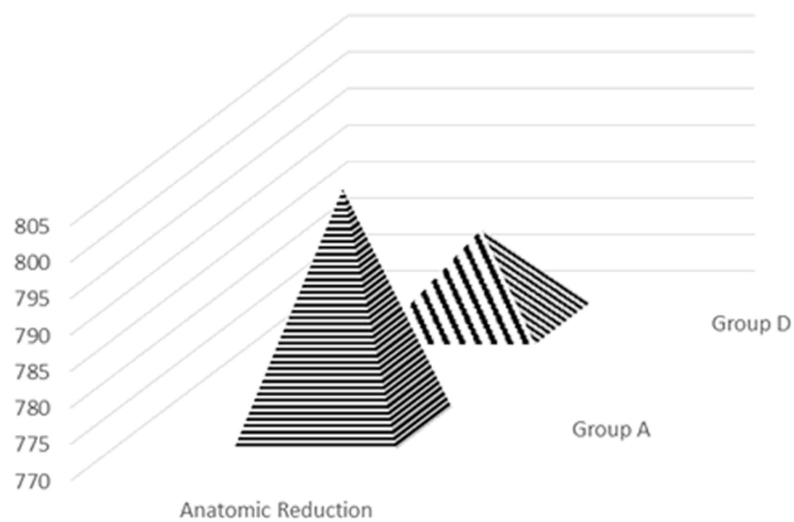

Figure 6. The load of the anatomic reduction model in Groups A and D.

PFNA can provide not only more reasonable angular stability, but also more stable support against pullout, rotation, excision, and varus deformities using minimally invasive techniques [12]. Reducing operation times and avoiding intraoperative accidents, sometimes the reduction of quality ensures the safety of the operation. A clinical retrospective study showed that, even if intertrochanteric fractures are not anatomically reduced, good clinical results can be achieved [4]. Positive and negative support reduction was first proposed by Gottfried [13], becoming the reduction criteria for femoral neck fractures in 2012. Chang SM used this positive support theory to treat intertrochanteric fractures successfully. The essence of the theory is that the fracture can obtain secondary stability without anatomical reduction, providing a relatively stable biomechanical environment for fracture healing.

Myung [14] found that patients in the positive support group had less neck shaft angle loss and lag screw migration than the negative support group, using DHS. Present results also showed that the positive support group was better than the other two groups. It was confirmed that positive support and anatomic reduction are better than negative support, according to biomechanical tests. Moreover, from the clinical retrospective study, it can be found that the proximal femur with negative support is easier to deform than the others. The proximal femur is more likely to become short. However, there were no significant differences between anatomic reduction and positive support [15]. It can be explained that, in positive support, the anterior and posterior cortex of the head and neck fragments were locked in the lateral view. The proximal medial cortex was found in the medial cortex of the femoral shaft. When subjected to vertical pressure, fragments of the head and neck first would slide along the axial direction of the spiral blade. The anterior and posterior cortices got compacted with each other. Continued stress on the head and neck fracture blocks produced a slight abduction that may cause the medial cortex of the femoral shaft to ward off the medial cortex of the head and neck fracture blocks, providing mechanical support and preventing the loss of fracture reduction. However, in the negative support, the proximal medial cortex of head and neck was found in the medial cortex of the femoral shaft. When the head and neck fracture block was varus, this stress was absent, compared with the positive support, resulting in the less extreme load of the negative support. The extreme load in the anatomic reduction group C was higher than that in the other two groups ($P < 0.05$). Due to the attachment of the iliopsoas muscle to the trochanter, the strength of the small trochanter area was stronger under strong stress stimulation. Compared with group B, the posteromedial wall of the small trochanter had more anti-varus strength than the anteromedial wall. After the removal of the posteromedial wall, the fragments of the head and neck had only the anteromedial cortex. The resistance to stress was greatly reduced, resulting in instability. In summary, the biomechanical stability of positive support in AO31A1 was the highest. There were no statistical differences in biomechanical stability between positive support and anatomic reduction in AO31A2 fractures with anteromedial wall loss. For AO31A2 fractures with posteromedial wall loss, anatomic reduction is suggested.

There was another issue concerning the medial wall or lateral wall of femoral intertrochanteric fractures that was more important. Defects in the intertrochanteric medial wall have been proven to postoperatively cause coxa vara and proximal femoral shortening after intertrochanteric fractures occur [16]. However, there were opposite results represented by Liu X [17]. The integrity of the trochanter hardly affected the postoperative recovery of intertrochanteric fractures. Schenkel M [18] also showed that less displaced trochanter (> 20 mm) can hardly affect the strength of hip flexion. Myung [14] also reported that wire-binding of medial wall fragments had no significant effects on the screw migration distance and neck shaft angle. From the above, the medial wall is believed to have few effects on stability. Current results showed that the absence of the medial wall had no significant differences in the stability after fracture reduction via PFNA-II internal fixation. Compared with eccentric fixation of extramedullary fixation system, the intramedullary fixation system was a central fixation system with shorter force arm and more stable mechanical properties. Therefore, the new AO classification, which took the integrality of the lateral wall as the criterion, was used as the main classification basis in this study. With a more reasonably designed intramedullary fixation system, the implant can provide mechanical support for medial wall defects. The lateral wall should be emphasized to improve the stability of the fracture after reduction and fixation, as opposed to the medial wall. Ehrnthaller C [19] showed that the reconstruction of the medial wall could significantly improve the stability of intertrochanteric fractures after internal fixation, with stiffness increasing by 38%. Present results showed that an extreme load (802.79 ± 70.64) in the presence of the medial wall was greater than that in the absence of the medial wall (782.89 ± 61.76), with stability increasing by 2.54%. However, there was no statistical significance. This difference may be caused by many factors. For example, the osteotomy methods and the different bones used in the studies may have led to differences. The scholar used the cadaver bones, while the current study used artificial bones. Therefore, the cadaver bones may be used in the future to reconfirm present results. In recent years, more and more scholars have focused on studying the effects of the lateral wall on stability. Palm H et al. [20] found that lateral wall fractures after intertrochanteric fractures were an important predictor of revision surgery. Pradeep AR et al. [21] also considered that the intact lateral wall plays an important role in the stability of intertrochanteric fractures. Therefore, for intertrochanteric fractures, especially unstable fractures, researchers should fully evaluate the effects of the lateral wall on postoperative stability. Whether additional treatment of the lateral wall was needed to strengthen the fixation of the lateral wall is an issue that should be investigated.

The current study was limited by the selection of bones. Artificial bone is a bionic bone made according to normal human anatomy parameters and its anatomical morphology is consistent with normal human bone structure. There were no significant differences between the artificial bones and human bones. However, there may be mechanical differences between artificial bones and cadaver bones. Results obtained from physical mechanical experiments, therefore, are uncertain due to individual differences. In this experiment, there were no vertical compressive experiments to simulate the process of standing up from a seat. Only mechanical results of the PFNA system in intertrochanteric fractures of the femur were tested. Whether other intramedullary systems can achieve the same results requires further confirmation.

In summary, for AO31A1 and A2 femoral intertrochanteric fractures, the most important step in treatment is anatomical reduction. However, if anatomic reduction cannot be achieved, mechanical stability of the positive support is better than that of the negative support. Moreover, if PFNA-II is used to treat intertrochanteric fractures, the loss of the medial wall has no effects on stability.

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