# A quantitative biomechanical study of positive buttress techniques for femoral neck fractures: a finite element analysis

Gang Wang[1], Bin Wang[1], Yong Tang[2], Hui-Lin Yang[1]

[1]Department of Orthopaedics, The First Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215006, China;
[2]Department of Orthopaedics, Southwest Hospital, Third Military Medical University, Chongqing 400038, China.

**Abstract**

**Background:** Refractory femoral neck fractures cannot be anatomically reduced by closed traction reduction which may affect fracture healing. We evaluated the biomechanical effects of positive, negative, and anatomic reduction of various degrees of displacement in Pauwels I femoral neck fractures by a finite element analysis.

**Methods:** Five reduction models of Pauwels type I femoral neck fracture were established using the Mimics 17.0 (Materialize, Leuven, Belgia) and Hypermesh 12.0 (Altair Engineering, Troy, MI, USA). According to the degree of fracture displacement, there were three models of positive support, an anatomic reduction model, and a negative 2 mm reduction model. Finite element analysis was conducted using the ABAQUS 6.9 software (Simulia, Suresnes, France). The von Mises stress distribution and the stress peak of internal fixation in different models, the displacement between fracture blocks, and the principal strain of the femoral neck cancellous bone model were recorded under the axial stress of 2100 N.

**Results:** The peak von Mises stress on screw of each model was located at the thread of the screw tip. The peak von Mises stress was the lowest at the tip of the anatomic reduction model screw (261.2 MPa). In the positive 4 mm model, the von Mises stress peak was the highest (916.1 MPa). The anatomic reduction model showed the minimum displacement (0.388 mm) between fracture blocks. The maximum displacement was noted in the positive 4 mm model (0.838 mm). The displacement in the positive 3 mm model (0.721 mm) was smaller than that in the negative 2 mm model (0.786 mm). Among the five models, the strain area of the femoral neck cancellous bone was mainly concentrated around the screw hole, and the area around the screw hole could be easily cut.

**Conclusions:** Compared with negative buttress for femoral neck fracture, positive buttress can provide better biomechanical stability. In Pauwel type I fracture of femoral neck, the range of positive buttress should be controlled below 3 mm as far as possible.

**Keywords:** Anatomical reduction; Femoral neck fracture; Finite element analysis

## Introduction

A femoral neck fracture is a common injury, which accounts for about 50% of hip fractures.[1] The two major complications of femoral neck fracture are fracture nonunion and avascular necrosis of the femoral head due to blood supply interruption. The diagnosis and treatment of femoral neck fracture still pose a challenge for orthopedic surgeons.[2-4] The treatment methods vary according to the age of patients and the type of fracture. Age has traditionally been considered an important factor for treatment selection. Joint replacement is the main treatment strategy for displaced femoral neck fractures in the elderly.[5] For femoral neck fracture in patients aged 65 years or younger, a closed reduction and internal fixation with femoral head preservation are considered the preferred treatment. In this case, the most common internal fixation method is the use of three parallel sliding hollow compression screws, which achieves good outcomes.[6]

| Access this article online | |
|---|---|
| Quick Response Code: | Website: www.cmj.org |
| | DOI: 10.1097/CM9.0000000000000490 |

Traditionally, the anatomic reduction is considered the key element to promote healing of the femoral neck fracture and to avoid complications.[7] To obtain the anatomic reduction, many scholars have described different reduction methods, such as the Leadbetter reduction method and the Flynn reduction method.[8,9] However, some refractory femoral neck fractures cannot be anatomically reduced by closed traction reduction, and repeated traction reduction may cause damage to the remaining blood supply, thus affecting fracture healing and the blood supply to the femoral head. In 2013, Gotfried *et al*[10] proposed the concept of positive buttress of a femoral neck fracture, which can also achieve good clinical efficacy. Positive buttress refers to the distal inferior margin of the femoral neck fracture located medial to the proximal inferior margin of the fracture. Negative buttress is opposite to the displacement direction. Many scholars have accepted this concept, and it offers a new option for the treatment of refractory femoral neck fractures.[11] It was reported that the bone-screw interface would generate

**Correspondence to:** Prof. Hui-Lin Yang, Department of Orthopaedics, The First Affiliated Hospital of Soochow University, Suzhou, Jiangsu 215006, China
E-Mail: suzhouyang1@163.com



Chinese Medical Journal 2019;132(21)
**Received:** 02-05-2019 **Edited by:** Ning-Ning Wang

stress as the femoral neck fracture end was absorbed through Gotfried reduction.[12] The cortical contact interface provided by positive buttress can disperse part of the stress. Thus, the risk of internal fixation failure is reduced. However, Gotfried *et al*[10] could not conduct a detailed and quantitative study of this technique due to the small number of cases reported. If the distal inner edge of the fracture is lower than the proximal lower edge, it will increase the instability of the fracture. However, the extent to which the distal inner margin of a fracture located lower than the proximal lower margin benefits the patients has not been reported in previous studies.

Therefore, to avoid overuse of the concept of positive support in clinical work, this study quantified the positive buttress technology for femoral neck fracture using the finite element method. The biomechanical stability of positive buttress (2, 3, and 4 mm), negative buttress (2 mm), and anatomic reduction of different degrees of displacement were compared. This study aimed to standardize the positive buttress technique from a biomechanics perspective and to guide the clinical application with this technique.

## Methods

### *Ethical approval*

This study was reviewed and approved by the Ethics Committee at the First Affiliated Hospital of Soochow University (No. 2019lsp158). Written informed consent was obtained from the healthy volunteer. A healthy femur of a male (28-year-old) with non-pathologic and normal low limb alignment bones was taken computed tomography (CT) scan at the First Affiliated Hospital of Soochow University. A 64 spiral CT scan (Philips, Eindhoven, Holland) was performed along the long shaft of the femur. The scanning range was from the pelvis to the talus, and we used CT images with a thickness of 0.64 mm. The physical distance of the lattice was 0.799 mm. Specimen was scanned using 64 spiral CT with the main scan parameters as follows: tube voltage 120 kV, tube current 200 mA. Images were exported and saved as Digital Imaging and Communications in Medicine (DICOM) format. Then the osteotomy plane was made above 10 cm from the femoral condyle as the distal osteotomy plane in the Mimics 17.0 (Materialize, Leuven, Belgia) and Hypermesh 12.0 software (Altair Engineering, Troy, MI, USA). Thus, the geometric model of the femur was established and five kinds of Pauwels type I femoral neck fracture reduction model (Pauwels angle of 30°) were rebuilt [Figure 1]. According to the degree of fracture displacement, there were three models (2, 3, and 4 mm) of positive support, an anatomic reduction model, and a negative reduction model. The 3-dimension (3D) models of cannulated compression screw (CCS) (diameter: 7.3 mm; thread length: 16 mm) were reconstructed using the software of Unigraphics NX 8.5 (Siemens PLM Software, Berlin, Germany). We completed the assembly of screws and bones in the Mimics17.0 software, and we simulated five reduction and fixation models of femoral neck fracture [Figure 2]. The screws were arranged in parallel inverted triangles, in which the lowest screw was not below the level of the small trochanter in each model. Screws in each group

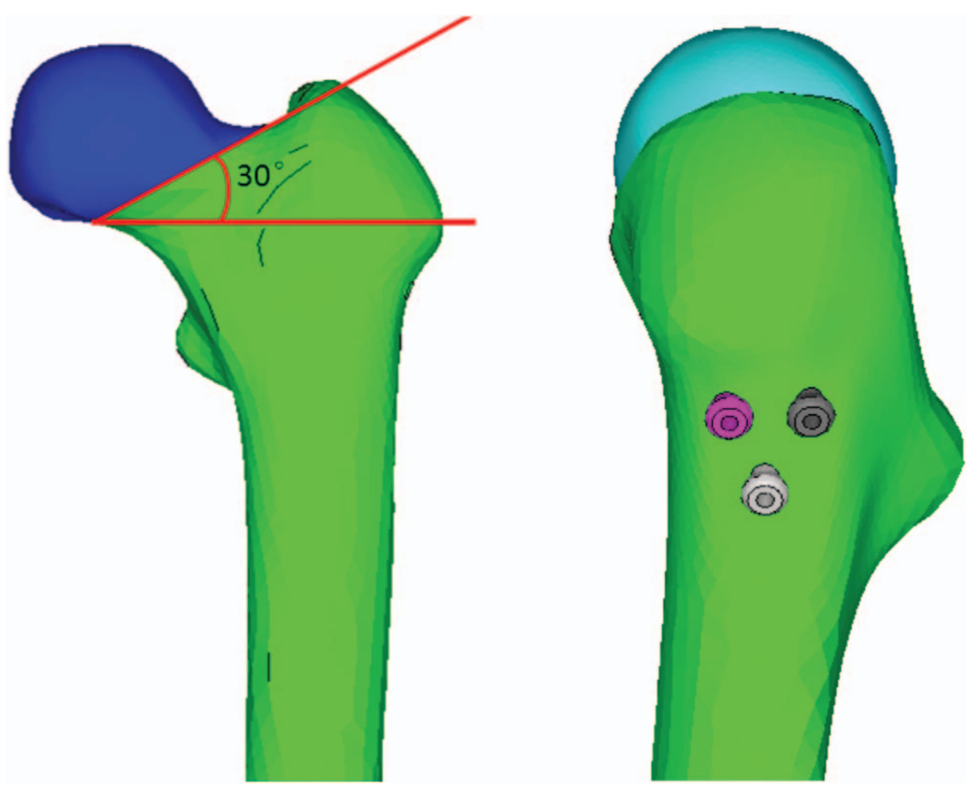


**Figure 1:** Fracture model and cannulated screw fixation.

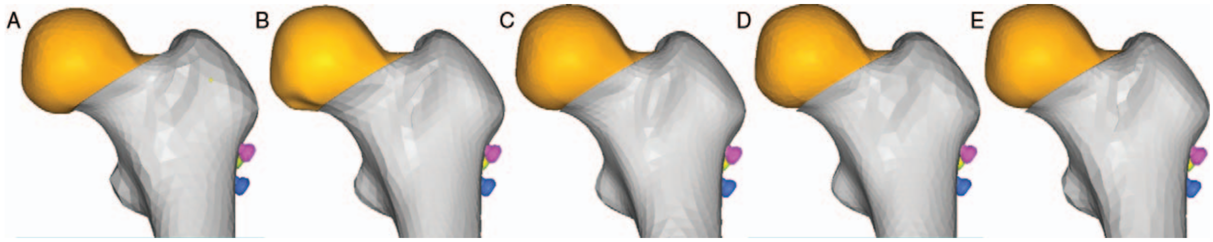


Figure 2: Post-operative model (partial local magnification of the femoral head): (A) negative buttress 2 mm; (B) anatomic reduction; (C) positive buttress 2 mm; (D) positive buttress 3 mm; (E) positive buttress 4 mm.

**Table 1: The details of models created in this study.**

| Prameters | Negative buttress 2 mm | Anatomic reduction 0 mm | Positive buttress 2 mm | Positive buttress 3 mm | Positive buttress 4 mm |
|---|---|---|---|---|---|
| Femur | | | | | |
| Nodes | 44,679 | 74,017 | 45,167 | 46,909 | 42,152 |
| Elements | 212,283 | 357,541 | 210,920 | 222,340 | 198,616 |
| Mesh size | Maximum: 4.5 mm; minimum: 0.5 mm | | | | |
| Screw | | | | | |
| Nodes | 20,258 | 47,372 | 20,802 | 17,783 | 20,947 |
| Elements | 65,109 | 173,919 | 66,662 | 56,629 | 67,245 |
| Mesh size | Maximum: 0.8 mm; minimum: 0.4 mm | | | | |

were placed close to the endosteal cortex. The software HyperMesh12.0 (Altair Engineering) was used for grid partitioning on all the models.

The assembled 3D model was imported using ABAQUS software (Simulia, Suresnes, France) to generate the finite element model. The screws were made of titanium alloy. The elastic modulus, Poisson ratio of titanium alloy and bone were performed as previously described.[13] Tetrahedral 10-nodes elements (C3D10) was used to simulate cortical bone, cancellous bone, and hollow screw of the femur. The effect of gravity was considered negligible in the model.[14] Frictional contact interactions between different parts of the model were assumed to exist. The internal cancellous bone and the cannulated screw thread of the femoral head were modeled using the common joint method. A friction coefficient of 0.3 was used to simulate the interface between the body and bone of the common hollow compression screw.[15] The friction coefficient of the interaction between the fracture end fragments was set at 0.46.[16] During the analysis, all nodes on the distal surface of the femur were constrained by 0 degrees of freedom to prevent rigid body movement. A load of 2100 N equivalent to three times the body weight was applied in the finite element model to introduce a force into the center of the femoral head. The force vector pointed laterally at an angle of 13° with the axis of the femoral shaft on the coronal plane and posteriorly at an angle of 8° with the shaft axis in the sagittal plane.[17] A major strain of 0.9% was taken as the yield strain value above which the bone was susceptible to yielding in accordance with previously published data.[18] Three parameters were used to capture the mechanical factors affecting the fixation stability and fracture healing of the five types of reduction and internal fixation, including the von Mises stress distribution and stress peak of the internal fixator, the displacement distribution of fracture fragments, and the principal strain of the femoral neck cancellous bone model. The distribution and maximum displacement of fracture fragments are the most critical factors to determine the stability of fracture reduction and fixation.

## Results

Parameters of models are summarized in Table 1.

### *Stress distribution and the peak value of internal fixation screws*

Stress distribution in the five reduction and fixation models shown in Figure 3. It was found that the peak von Mises stress of screw on each model was located on the thread surface of the screw tip, and the maximum stress was sustained by two screws close to the femoral calcar. The peak value of screw stress was 916.1 MPa in the positive 4 mm model. The lowest stress peak value was 261.2 MPa, which was found in the anatomic reduction model. The stress peak value in the positive 2 mm model screw was 358.2 MPa, which was close to that in the anatomic reduction model. The stress peak value in the negative 2 mm model (705.8 MPa) was between the values of the positive 3 mm model (526.4 MPa) and the positive 4 mm model (916.1 MPa).

### *Displacement between fracture fragments*

Differences in fracture block displacement were observed among the five reduction models. Inter-fragmentary motions were calculated as the displacements between

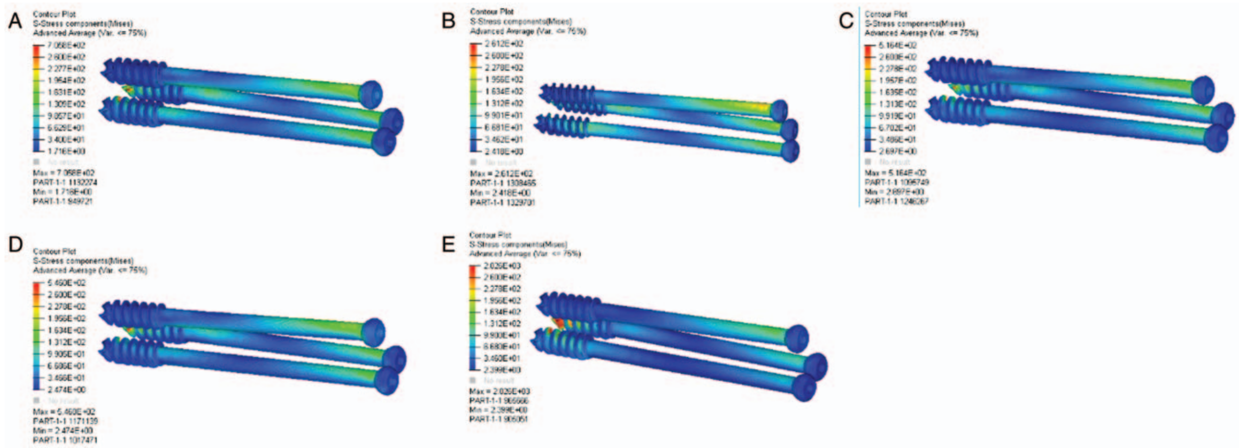


**Figure 3:** Internal fixation stress distribution in the five reduction models: (A) negative buttress 2 mm; (B) anatomic reduction; (C) positive buttress: 2 mm; (D) positive buttress 3 mm; (E) positive buttress 4 mm.

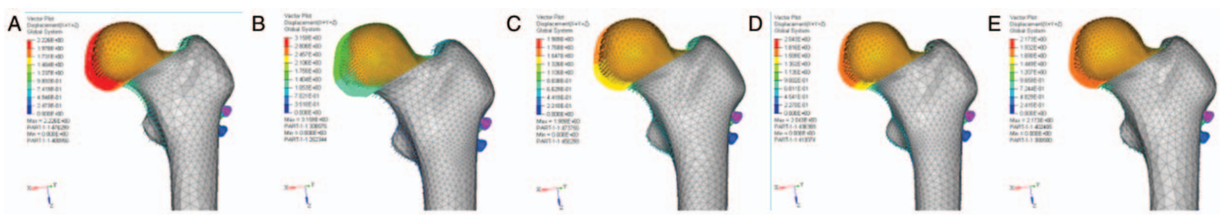


**Figure 4:** Fracture block displacement vector of the five models: (A) negative buttress 2 mm; (B) anatomic reduction; (C) positive buttress: 2 mm; (D) positive buttress 3 mm; (E) positive buttress 4 mm.

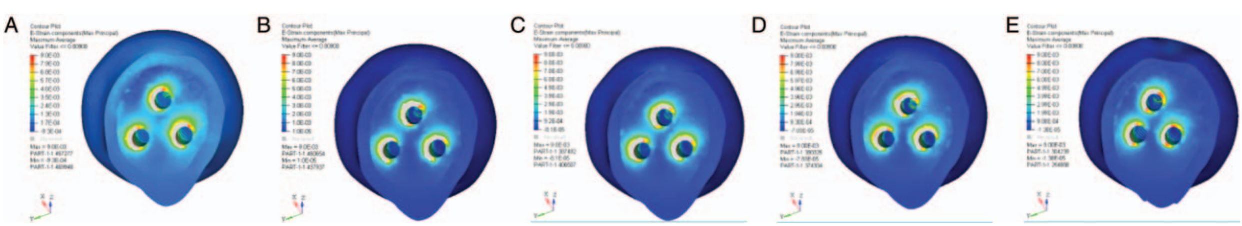


**Figure 5:** Strain cloud of femoral neck cancellous bone in yield strain 0.9% in the five reduction models. The orange and red parts are larger than the yield strain, indicating the risk of failure: (A) negative buttress 2 mm; (B) anatomic reduction; (C) positive buttress: 2 mm; (D) positive buttress 3 mm; (E) positive buttress 4 mm.

the two nodes on the proximal end of the fracture gap on the coronal view. The anatomic reduction model showed the smallest displacement of a fractured block, and it was 0.388 mm. The displacement value in the positive 2 mm model was 0.547 mm, which was close to the values found in the anatomic reduction model. The maximum displacement in the negative 2 mm model (0.786 mm) was between the values of the positive 3 mm model (0.721 mm) and the 4 mm model (0.838 mm) [Figure 4].

### *Main strain of the femoral neck cancellous bone model*

Figure 5 shows the primary strain diagram of the proximal cancellous bone across the femoral neck. In the five models, the strain areas of the femoral neck cancellous bone were mainly concentrated around the nail holes. The area around the nail hole was the easiest to cut.

## Discussion

In this study, we conducted a finite element analysis to investigate whether there were mechanical differences in the treatment of Pauwels I femoral neck fractures with different levels of displaced positive buttress, negative buttress, and anatomic reduction. This study showed that the anatomic reduction model had the minimum internal fixation stress and the minimum fracture fragment displacement. The internal fixation stress and fracture block displacement in the positive buttress 2 mm model were close to those in the anatomic reduction model. The internal fixation stress and fracture block displacement in the negative buttress model were between those values of the 3 and 4 mm models.

In this study, Pauwels I femoral neck fracture was adopted as the fracture model because the shear angle of the

Pauwels I femoral neck fracture line was small. After positive buttress, it is easier to perform the abduction and insertion of the fractured end so that the fractured end tends to be stable, which is consistent with the concept of the Gotfried reduction method. Concerning the selection of the internal fixation model, the more stable fixation method is the inverted triangle parallel hollow compression screw fixation, which has been confirmed in many studies.[19] Previous studies on finite element analysis of femoral neck fractures were limited to the selection of internal fixators and configurations.[20]

The concept of the Gotfried reduction technique is to stabilize unstable sub-cephalic fractures.[21] The primary mechanism is that positive buttress can provide better biomechanical stability.[22] If excessive pressure is generated on the bone-screw interface due to sliding tension of the cannulated nail, the femoral head may be displaced (with the possibility of "cutting out"). The medial femoral cervical cortex is markedly thick, and positive buttress reduces the screw stress when incisions occur, possibly due to the provision of cortical-cortical contact. Under axial load, compared with the stress in the negative buttress model, the stress in the positive buttress 2 and 3 mm model screws were smaller. This is because positive buttress can dissipate some of the screw stress. The stress in the positive buttress 4 mm model screw was higher than that in the negative buttress model. This may be due to the inability of the positive buttress to provide cortical to cortical contact after displacement. Under the action of the axial load, the fracture clearance displacement in the anatomic reduction model is the smallest. The fracture clearance displacement in the positive buttress 2 and 3 mm models was smaller than the displacement in the negative buttress 2 mm model. The fracture clearance displacement in the 4 mm model with positive buttress was the largest. Therefore, the stability of the positive buttress model was the closest to the stability provided by the anatomic reduction model. The stability of the 2 mm model of negative buttress was between the ones of the 3 and 4 mm models of positive buttress. All the main strain areas of the femoral neck cancellous bone model were concentrated around the three nail holes. Excessive stress may result in deformation of the cancellous bone around the cannulated nail. This causes cutting of the screws. The results of this study also confirmed the mechanism of Gotfried reduction and provided a quantitative analysis of the positive buttress technology to a certain extent, which has a positive guiding significance for clinical research.

According to the results of this study, positive buttress was graded and set as positive reduction level I (shift 0–2 mm). Positive 3 mm buttress was more stable than negative 2 mm buttress, and it was set as positive reduction level II (displacement 2–3 mm). Positive 4 mm support reset had poor stability, and it was set as positive reset level III (displacement 3–4 mm). The reset above 4 mm was set as positive reset level IV (shift >4 mm). Therefore, when anatomic reduction cannot be achieved during surgical reduction, positive reduction level I can also provide relatively stable biomechanical effects. Positive reset level II is a relatively acceptable range. Positive reset level III is not recommended. Positive reset level IV should be avoided as much as possible.

Our study has some limitations. First, our finite element analysis is only based on a healthy object, which is similar to the other finite element analyses.[23] To confirm our findings, a multi-centric retrospective study in many patients with femoral neck fractures who underwent positive buttress techniques is required. The biomechanical stability of femoral neck fracture healing is only one of the important factors. Other factors including age, fracture type, and reduction style can affect fracture healing. Second, there is no experimental verification. However, we aim to study trends, not absolute values. In this regard, the lack of experimental verification is reasonable. The previous experimental verification numerical study used the same loading and boundary conditions as our study.[24] In the later stage, more realistic biomechanical experiments and clinical trials are needed to overcome the limitations of this study. Finally, this paper studied the CT image simulation reconstruction model based on the finite element analysis method. However, the actual procedure is much more complicated than the experiment. This study only simulated proximal femoral cortical and cancellous bones, and it did not simulate the femoral calcar. Therefore, the quantitative grading of positive support for femoral neck fracture set in this study can only serve as a clinical reference, and the finite element experiment of Pauwels II and III femoral neck fracture positive buttress should be completed in the future.

In conclusion, although the quantitative grading of femoral neck fracture positive buttress from the perspective of biomechanical stability has certain limitations, it still has guiding significance for clinical practice. In the clinical closed reduction of a femoral neck fracture, anatomical reduction or grade I reduction should be attempted where possible.

## Funding

This study was partially supported by a grant from the Zhejiang Medical Science Foundation of China (No. 2019KY682).

## Conflicts of interest

None.

## References

1. Unnanuntana A, Saiyudthong N. Outcomes of cerclage wiring to manage intra-operative femoral fracture occurring during cementless hemiarthroplasty in older patients with femoral neck fractures. Int Orthop 2019. [Epub ahead of print]. doi: 10.1007/s00264-019-04327-9.
2. Stockton DJ, Dua K, O'Brien PJ, Pollak AN, Hoshino CM, Slobogean GP. Failure patterns of femoral neck fracture fixation in young patients. Orthopedics 2019;42:e376–e380. doi: 10.3928/01477447-20190321-03.
3. Svenoy S, Westberg M, Figved W, Valland H, Brun OC, Wangen H, *et al*. Posterior versus lateral approach for hemiarthroplasty after femoral neck fracture: early complications in a prospective cohort of 583 patients. Injury 2017;48:1565–1569. doi: 10.1016/j.injury.2017.03.024.
4. Jo S, Lee SH, Lee HJ. The correlation between the fracture types and the complications after internal fixation of the femoral neck fractures. Hip Pelvis 2016;28:35–42. doi: 10.5371/hp.2016.28.1.35.
5. Sassoon A, D'Apuzzo M, Sems S, Cass J, Mabry T. Total hip arthroplasty for femoral neck fracture: comparing in-hospital mortality, complications, and disposition to an elective patient population. J Arthroplasty 2013;28:1659–1662. doi: 10.1016/j.arth.2013.01.027.

6. Wang G, Tang Y, Wang B, Yang H. Minimally invasive open reduction combined with proximal femoral hollow locking plate in the treatment of Pauwels type III femoral neck fracture. J Int Med Res 2019;47:3050–3060. doi: 10.1177/0300060519850962.
7. Wang Y, Ma JX, Yin T, Han Z, Cui SS, Liu ZP, *et al*. Correlation between reduction quality of femoral neck fracture and femoral head necrosis based on biomechanics. Orthop Surg 2019;11:318–324. doi: 10.1111/os.12458.
8. Eamsobhana P, Keawpornsawan K. Nonunion paediatric femoral neck fracture treatment without open reduction. Hip Int 2016;26:608–611. doi: 10.5301/hipint.5000382.
9. Kwon HM, Lim S, Yang IH, Lee WS, Jeon BH, Park KK. Impact of renal function on the surgical outcomes of displaced femoral neck fracture in elderly patients. J Clin Med 2019;8:E1149. doi: 10.3390/jcm8081149.
10. Gotfried Y, Kovalenko S, Fuchs D. Nonanatomical reduction of displaced subcapital femoral fractures (Gotfried reduction). J Orthop Trauma 2013;27:e254–e259. doi: 10.1097/BOT.0b013e31828f8ffc.
11. Kazley JM, Banerjee S, Abousayed MM, Rosenbaum AJ. Classifications in brief: garden classification of femoral neck fractures. Clin Orthop Relat Res 2018;476:441–445. doi: 10.1007/s11999.0000000000000066.
12. Xiong WF, Changm SM, Zhang YQ, Hu SJ, Du SC. Inferior calcar buttress reduction pattern for displaced feoral neck fractures in young adults: a preliminary report and an effective alternative. J Orthop Surg Res 2019;14:70. doi: 10.1186/s13018-019-1109-x.
13. Goffin JM, Pankaj P, Simpson AH, Seil R, Gerich TG. Does bone compaction around the helical blade of a proximal femoral nail anti-rotation (PFNA) decrease the risk of cut-out?: a subject-specific computational study. Bone Joint Res 2013;2:79–83. doi: 10.1302/2046-3758.25.2000150.
14. Zhang H, Li J, Zhou J, Li L, Hao M, Wang K, *et al*. Finite element analysis of different double-plate angles in the treatment of the femoral shaft nonunion with no cortical support opposite the primary lateral plate. BioMed Res Int 2018;2018:3267107. doi: 10.1155/2018/3267107.
15. Panteli M, Rodham P, Giannoudis PV. Biomechanical rationale for implant choices in femoral neck fracture fixation in the non-elderly. Injury 2015;46:445–452. doi: 10.1016/j.injury.2014.12.031.
16. Yang JJ, Lin LC, Chao KH, Chuang SY, Wu CC, Yeh TT, *et al*. Risk factors for nonunion in patients with intracapsular femoral neck fractures treated with three cannulated screws placed in either a triangle or an inverted triangle configuration. J Bone Joint Surg Am 2013;95:61–69. doi: 10.2106/JBJS.K.01081.
17. Mitchell RJ, Kay AB, Smith KM, Murphy SB, Le DT. Early results of displaced femoral neck fragility fractures treated with supercapsular percutaneous-assisted total hip arthroplasty. Arthroplasty today 2019;5:193–196. doi: 10.1016/j.artd.2019.02.003.
18. Li J, Wang M, Li L, Zhang H, Hao M, Li C, *et al*. Finite element analysis of different configurations of fully threaded cannulated screw in the treatment of unstable femoral neck fractures. J Orthop Surg Res 2018;13:272. doi: 10.1186/s13018-018-0970-3.
19. Li J, Wang M, Zhou J, Han L, Zhang H, Li C, *et al*. Optimum configuration of cannulated compression screws for the fixation of unstable femoral neck fractures: finite element analysis evaluation. BioMed Res Int 2018;2018:1271762. doi: 10.1155/2018/1271762.
20. Papachristos IV, Rankine J, Giannoudis PV. Hip arthrodiastasis combined with core decompression and diamond concept for postcollapse femoral head avascular necrosis. BMJ case Rep 2019;12:e231081. doi: 10.1136/bcr-2019-231081.
21. Dheenadhayalan J, Prasad VD, Devendra A, Rajasekaran S. Impaction bone grafting and valgus osteotomy - a technical trick for the treatment of femoral neck nonunions. J Orthop Trauma 2019;33:e403–e408. doi: 10.1097/BOT.0000000000001564.
22. Siebenburger G, Helfen T, Biermann N, Haasters F, Bocker W, Ockert B. Screw-tip augmentation versus standard locked plating of displaced proximal humeral fractures: a retrospective comparative cohort study. J Shoulder Elbow Surg 2019;28:1326–1333. doi: 10.1016/j.jse.2018.12.001.
23. Gardner MP, Chong AC, Pollock AG, Wooley PH. Mechanical evaluation of large-size fourth-generation composite femur and tibia models. Ann Biomed Eng 2010;38:613–620. doi: 10.1007/s10439-009-9887-7.
24. Yin W, Xu Z, Sheng J, Zhang C, Zhu Z. Logistic regression analysis of risk factors for femoral head osteonecrosis after healed intertrochanteric fractures. Hip Int 2016;26:215–219. doi: 10.5301/hipint.5000346.


**How to cite this article:** Wang G, Wang B, Tang Y, Yang HL. A quantitative biomechanical study of positive buttress techniques for femoral neck fractures: a finite element analysis. Chin Med J 2019;132:2588–2593. doi: 10.1097/CM9.0000000000000490