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# Medial anatomical buttress plate in treating displaced femoral neck fracture a finite element analysis

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ABSTRACT

*Background:* Displaced femoral neck fractures in young adults are most likely to result from high energy trauma that causes a vertically-oriented shearing injury through the femoral neck. The optimal strategy for treatment of displaced femoral neck fractures remains an unsolved challenge in orthopedic surgery.
*Methods:* our group has previously designed a medial anatomical buttress plate (MABP) based on the analysis of the computed tomography (CT) data of anatomical structures derived from a large sample population. In this study, finite element analyses (FEA) were carried out to compare the outcomes of the combination of our MABP with cannulated screws to those of the combination of tubular plate with cannulated screws, and to those of using cannulated screws alone.
*Results:* MABP resulted in a more stable fixation as compared to the other two approaches, with respect to the femur and the stress distributions, stress peaks, and Z axis displacements.
*Conclusions:* The FEA encouraged us that addition of a medial buttress plate not only achieved superior medial buttress stability but also achieves superior performance because it perfectly fits with the existing anatomic structure of medial femoral neck. The results from our study may provide references for clinical decision making in dealing with such patients.


## Introduction

Displaced femoral neck fractures in young adults are most likely to result from high energy trauma that causes a vertically-oriented shearing injury through the femoral neck [1–3]. Based on the verticality of the fracture, Pauwels has classified these fractures as being either type II – angle 30–50°, and type III – angle greater than 50° [4,5]. Greater fracture verticality contributes to greater difficulty in obtaining adequate stability to resist vertical shear forces around the hip, thereby resulting in ascending greater risk of complications despite a number of potential fixation strategies [6]. Previous studies have shown that approximately 20–60% patients with displaced femoral neck fractures experienced post-operative complications including avascular necrosis (AVN), mal-union, and nonunion [7,8].

The optimal strategy for treatment of displaced femoral neck fractures remains an unsolved challenge in orthopedic surgery. Three cannulated lag screws placed in parallel along the femoral neck axis are frequently applied in clinical practice. However, this procedure has a high risk of failure due to the shear forces mentioned above, especially for the treatment of type III fractures [9]. Previously reported failure rates using parallel screws ranged from 10% to 30%, with patients experiencing complications such as backing-out of the cannulated screws, nonunion, and osteonecrosis of the femoral head [10,11]. To tackle this challenge, Mir and Collinge conceptualized incorporating a medial buttress plate into the treatment of displaced femoral neck fractures [12]. This idea was based on the application of buttress (or “anti-glide”) plate fixation to support bones in fractures such as tibial fractures and distal radial fractures, which also require resistance to shear forces in order to achieve stability in response to compression or axial loading [13–16]. Application of a buttress plate over the apex of the displaced femoral neck fracture where it can act to convert shear forces into compressive forces to achieve so-called Medial Buttress Stability (MBS) was therefore proposed. Based on this concept, a novel procedure combing cannulated screws with a medial-buttress 1/3 tubular plate was developed. Using this procedure, Hak et al. [17] reported an improved fracture union rate relative to historical controls that had used cannulated screws alone.

*Abbreviations:* FEA, finite element analysis; TP, tubular plate; MABP, medial anatomical buttress plate.

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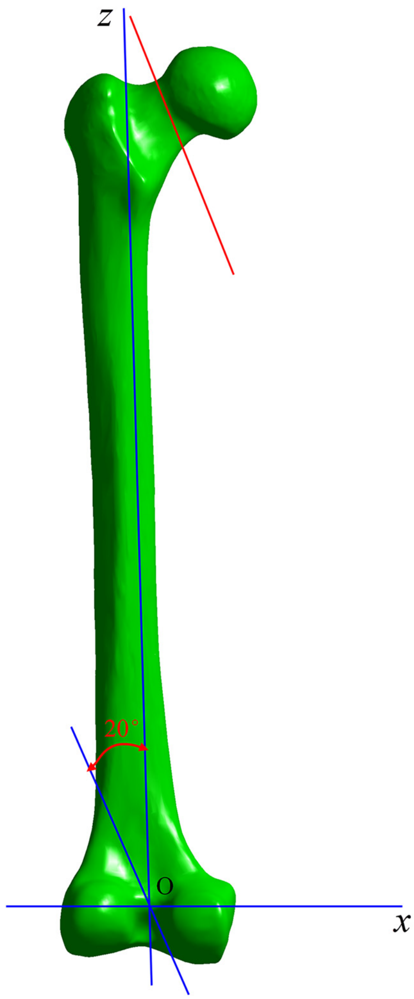


**Fig. 1.** Femoral neck fracture line structure: The blue line ZO is the the axis of the femoral shaft; the pink line is the fracture line of the femoral neck, the angle of complement of this angle (20°) is the angle of the femoral neck fracture.

Nonetheless, implant failure was still observed in 3 cases (of 27 total), and was associated with femoral neck shortening. Reduction loss with backing-out of the cannulated screws occurred in these cases, and in one case there was also plate and screw breakage. More problematically, shaping the contour of the 1/3 tubular plate so that it matches the anatomy of the medial arch of the femoral neck to produce sufficient buttressing force is time-consuming, potentially adversely affecting patients' prognoses.

Accordingly, Our group has previously designed a medial anatomical buttress plate (MABP, Patent No. CN 105520774 B) based on the analysis of the computed tomography (CT) data of anatomical structures of femoral neck. In this study, finite element analyses (FEA) were carried out to compare the outcomes of the combination of our MABP with cannulated screws to those of the combination of tubular plate with cannulated screws, and to those of using cannulated screws alone. Our aim was to further verify the clinical significance of achieving medial buttress stability as well as to quantify the outcomes achieved by MABP and tubular plates in treating displaced femoral neck fractures. The results from our study may provide references for clinical decision making in dealing with such patients.

## Materials and methods

### *Three-dimensional modeling of the femoral neck fracture*

A three-dimensional model of the Sawbones® left fourth-generation composite femur (Model 3406; Sawbones, Vashon, WA) was used for the geometric model of the femur.

Then, we used 3-matic (Materialize, Belgian) to simulate the Pauwels type III unstable fracture [18]. We first created the femoral shaft axis, a cross which a sagittal plane was created. Then, we created a cutting plate that was across the center of the femoral neck at an angle of 20° with respect to the sagittal plane of the shaft axis. The femoral neck was cut by the cutting plane, simulating a Pauwels type III fracture (Fig. 1).

### *Geometric modeling of internal fixation of a femoral neck fracture*

Using Solidworks software(Dassault, France), according to the clinical fixation program and engineering geometric data modeling, three kinds of internal fixation models (CCS, CCS + 1/3 tubular plate, and CCS + MABP) were established. Threaded screw sections were simplified as a solid cylinder, and screw holes on the steel plate are also omitted. The specific models were as follows (Fig. 2). Each assembly is meshed by solid187 tetrahedral elements in the workbench software(Ansys, USA), and the grid convergence calculations are tested by different sizes. The statistics of three assembly elements and the total numbers of nodes were as follows (Table 1).

### *Computation and loading*

*Material parameters*

For modeling purposes, it was assumed that the cortical bone, cancellous bone, and femoral neck plate and locking screw were all continuous, isotropic and uniform linear elastic materials. The list


**Fig. 2.** Geometric modeling of internal fixation of femoral neck fracture.

**Table 1**
The statistics of three assembly elements and the total amount of nodes.

| Case group | nodes | elements |
|---|---|---|
| CCS | 220032 | 142647 |
| CCS + 1/3 TP | 269846 | 172870 |
| CCS + MABP | 293956 | 188276 |

**Table 2**
Bone and internal fixation material properties.

| Material name | Elastic Modulus (MPa) | Poisson's ratio |
|---|---|---|
| Cortical bone | 16350 | 0.26 |
| Cancellous bone | 137 | 0.3 |
| Titanium alloy | 110000 | 0.3 |

of parameters [19,20] for each component used in the calculation is as follows (Table 2):

*Contact settings*

According to the contact method described in previous studies [19,21], the fracture surface was set to friction, with a friction coefficient of 0.46, frictional contact was also used between the titanium plate and the bone surface, with a friction coefficient of 0.3, the screw-bone interface in all cases was assumed to be fixed.

*Apply loads and constraints*

For calculation purposes, the distal end of the femur was completely fixed. To mimics the single leg standing position [22], each calculated assembly model was abducted 10°, tilted backward by 9°, and statically loaded with a downward vertical force of 2100 N corresponding to 300% body weight, and the force was introduced to the center of the femoral head [23], as shown in Fig. 3 below.

*The shear force*

In this study, one plane was defined by the direction of the load, and another plane was defined by the fracture plane. The line of intersection between the two planes was the direction of the shear force. In order to better study the effect of internal fixation against this shear force, we defined this direction as the Z axis, with the X axis being perpendicular to the fracture plane, and the other direction being the Y axis (Fig. 4).

## Results

The stress distributions, stress peaks, and Z axis displacements of femur and three internal fixations were examined. Table 3 and Fig. 5 detail these results

*Stress distribution*

Differences of stress distribution were observed on the three configurations and the femur. The peak Von Mises stresses at the femoral head were 116.32 MPa, 114.91 MPa, and 112.59 MPa in CCS, CCS + 1/3 T P, and CCS + MABP, respectively. The peak Von Mises stresses at the site of internal fixation were 363.43 MPa, 510.69 MPa, and 294.55 MPa in CCS, CCS + 1/3 T P, and CCS + MABP, respectively (Table 3 and Fig. 5).

*Displacement*

The maximum femoral head displacement and internal fixation were also documented. The femur displacements were 8.1479 mm, 7.7878 mm and 7.5167 mm in CCS, CCS + 1/3 T P, and CCS + MABP,

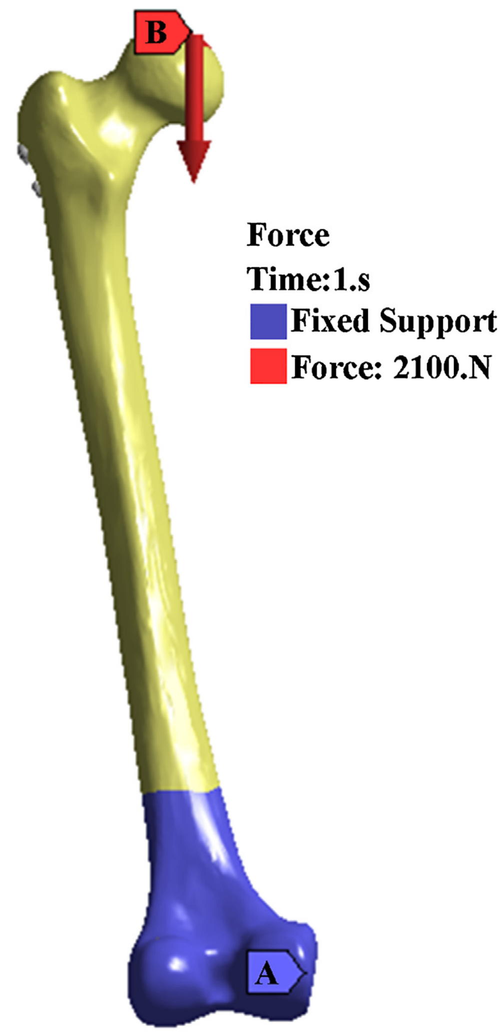


**Fig. 3.** A. The blue area means distal femur is fixed; B. Red arrow is the direction of the force.

respectively. The maximum internal fixation displacements were 7.9592 mm, 7.6115 mm and 7.3831 mm in CCS, CCS + 1/3 T P, and CCS + MABP, respectively.

Z axis represents the shear force direction. The Z axis displacements were 2.1701 mm, 2.1188 mm and 2.0504 mm in CCS, CCS + 1/3 T P, and CCS + MABP, respectively, as we can see that the CCS + MABP has the miThese results demonstrate that the CCS + MABP group exhibited less displacement than did the other two groups.

## Discussion

The principal findings of this study were: 1) Addition of a medial buttress plate achieved superior medial buttress stability as compared to cannulated screw fixation alone, suggesting superior healing of displaced femoral neck fractures; 2) As compared to addition of 1/3 T P, the application of MABP achieves superior performance because it perfectly fits with the existing anatomic structure of medial femoral neck.

Approaches to treating displaced femoral-neck fractures remain controversial, especially in younger patients (<65 years old). Arthroplasty is usually rules out quickly, given that arthroplasty implants generally do not last more than 20 years and can cause multiple complications including infections and dislocations [24,25]. Unfortunately, when traditional internal

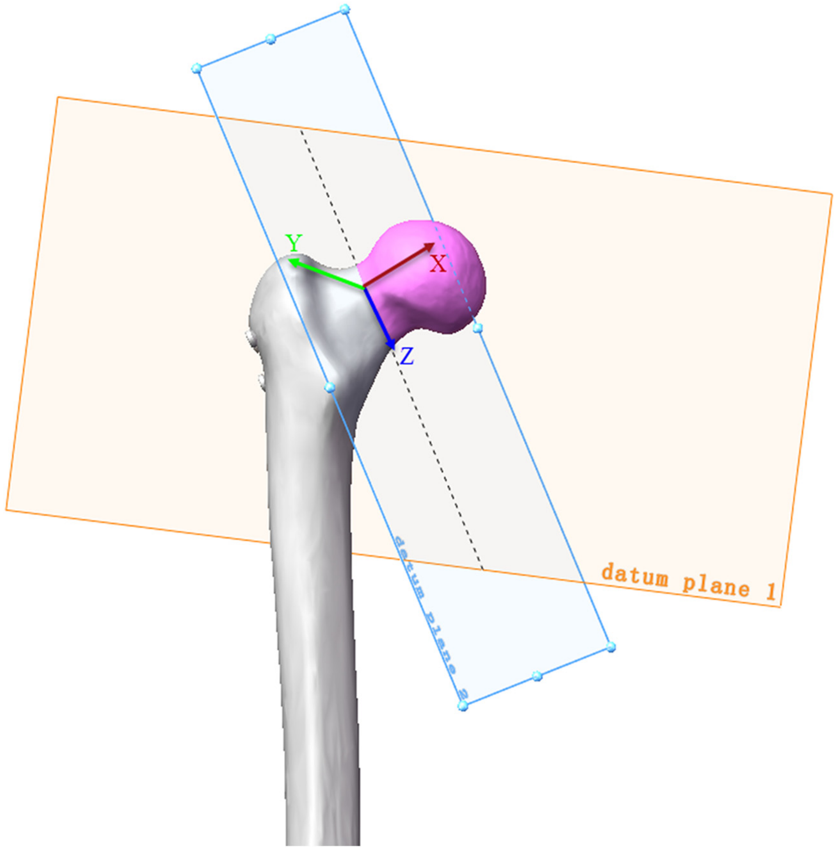


**Fig. 4.** Blue area is fracture plane; the red area is the loading force plane, the dashed line represents the direction of the shear force (Z axis).

**Table 3**
Parameters Results.

| Parameters | CCS | CCS + 1/3 T P | CCS + MABP |
|---|---|---|---|
| The maximum displacement of the femur (mm) | 8.1479 | 7.7878 | 7.5167 |
| The maximum displacement of the Internal fixation (mm) | 7.9592 | 7.6115 | 7.3831 |
| Maximum femur stress (MPa) | 116.32 | 114.91 | 112.59 |
| Internal fixation maximum stress (MPa) | 363.43 | 510.69 | 294.55 |
| The maximum displacement of Z axis (mm) | 2.1701 | 2.1188 | 2.0504 |

fixation strategies using three or four cannulated screws or sliding hip screws are used, poor outcomes such as fixation failure and non-union often result. As understanding of the underlying fracture mechanics has improved, clinicians have been able to better understand and explain these poor outcomes. The dominance of shear forces in displaced femoral neck fractures, particularly in the case of vertical fractures, causes femoral head toggling. It is thus vital that any fixation method be capable of resisting these shear forces during the process of bone healing, and cannulated screws are not able to do so. To address this issue, sliding hip screws such as the dynamic hip screw (DHS) were developed. Unfortunately, biomechanical experiments show that these screws only confer a slight increase in shear force resistance [26]. In addition, as only a single DHS is used, has a reduced ability to resist rotational force relative to the use of multiple cannulated screws [27,28]. Consequently, patients treated with DHS are more likely to experience a rotational displacement of the femoral head.

The novel approach of using medial buttresses to provide resistance to shear forces has been described to address the abovementioned issues. Buttress plates placed against the medial cortical bone have been previously reported. Sarat C. Kunapuli et al. [29] introduced an augmenting fixation with a 2.7-mm limited contact dynamic compression (LCDC) plate, contoured to fit along the anterior. Subsequently, Hak et al. [17] reported a novel procedure that combines cannulated screws with a medial-buttress 1/3 tubular plate, which is contoured during surgery based on the patients' anatomical structure. According to David et al., union without femoral neck shortening was achieved in 89% of cases using this approach. This union rate was higher than that observed in historical controls in whom cannulated screws alone had been used. However, using this approach resulted in some instances of implant failure, including the backing out of the cannulated screws as well as plate and screw breakage. Based on these results, clinical attention has shifted away from merely applying a pre-constructed buttress plate towards creating novel buttress plates specifically designed to fit within the mechanical environment of a femoral neck fracture.

In this study, we initially investigated the mechanical changes when a 1/3 tubular plate was added as compared to cannulated screws alone in order to clarify the strengths and weaknesses of such an approach. Our FEA results showed that the maximum displacement of both femur and internal fixation was reduced by the addition of the buttress plate, implying that this plate enhanced stability. In addition, the displacement in the direction

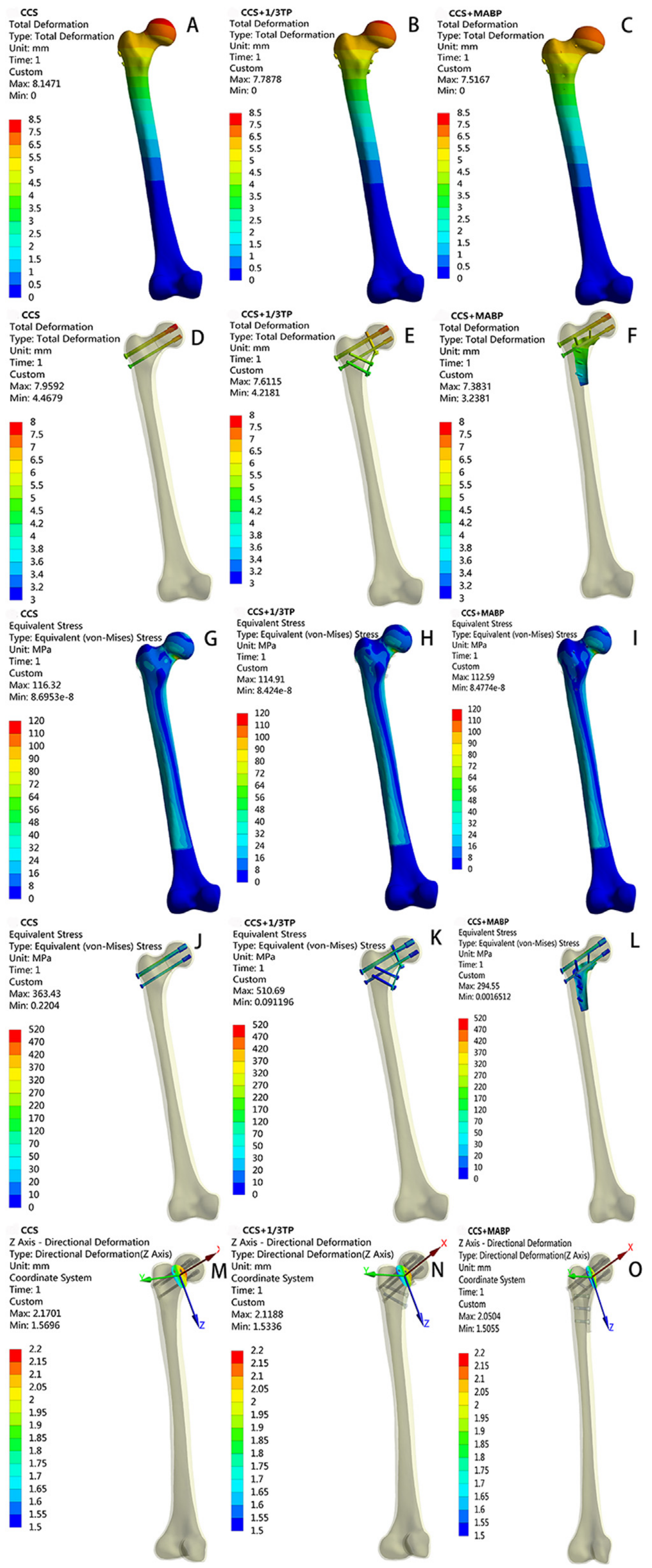


**Fig. 5.** A–C.The displacement of femur; D–F. The displacement of internal fixation. G–I. The stress of the femur; J–L. The stress of the femur internal fixation. M–O. The displacement of Z axis (it represent the shear force direction).

of shear force (the Z-axis) was found reduced as well. However, the analysis of the stress on the internal fixation showed an increase in mechanical stress on the screws and the medial buttress plate in this setting. This may explain the breakage of plate screws observed in the study of Hak et al., given that our FEA located maximal stress at this same site. We next performed similar analyses assessing our newly-designed implants. These results showed that addition of a MABP achieved better stability relative to both the CCS only group and the CCS + 1/3 TP group. More importantly, stress on the MABP was lower than in the other two groups. The explanation for this reduction may be that the MABP is designed to anatomically fit to the femur, providing a better buttressing force to the fracture fragments and better distributing stress transduced by the bone along the entire plate. This may reduce the risk of screw or/and plate breakage, although further biomedical experiments are required to confirm the hypothesis.

During the design process, our original goal was to combine the MABP with DHS, given that DHS alone already provides better shear force resistance, and screws inserted from the MABP may offer improved resistance to torsional forces. However, using this design, two incisions must be made in order to implant these fixations. Also previous biomechanical experiments showed that the resistance to the shearing force between DHS + buttress plate and CCS + buttress plate did not differ significantly. Therefore, a combination of MABP and CCS was applied instead.

## Conclusion

The FEA encouraged us that in the following biomechanical experiment, addition of a medial buttress plate not only achieved superior medial buttress stability but also achieves superior performance because it perfectly fits with the existing anatomic structure of medial femoral neck. Much as is the case for other FE analyses, studies using a larger cohort or randomized controlled studies including patients who require femoral neck fixation are needed in order to formally confirm our findings.

## Ethics approval

This article does not contain any studies with human participants or animals performed by any of the authors.

## Author contributions

Peifu Tang and Hua Chen developed the plate and helped in the design of the study; Jia Li helped in the conduction of the experiments, performed the evaluation of the data and their interpretation, and drafted the manuscript, revised the manuscript; Pengbin Yin helped in conduction the study and drafted the manuscript, Licheng Zhang supervised the study and revised the manuscript. All authors have read and approved the final version of the submitted manuscript.

## Availability of data and material

Data and materials were accessible in the case system at our department.

## Consent for publication

Not applicable.

## Funding

There is no funding to this study.

## Declaration of Competing Interest

All authors declare that they have no conflicts of interest concerning this study.

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