Int J Clin Exp Med 2017;10(10):14888-14894
www.ijcem.com /ISSN:1940-5901/IJCEM0045162

Original Article

Biomechanical evaluation of an improved PFNA fixation devices for intertrochanteric hip fracture with finite element analysis

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Received July 10, 2016; Accepted February 11, 2017; Epub October 15, 2017; Published October 30, 2017

Abstract: The intramedullary nails fixation system is widely used to cure intertrochanteric hip fracture. However, the traditional PFNA (Proximal Femoral Nail Antirotation) fixation system still exists some disadvantages in clinical applications. In this research, we designed an improved PFNA fixation system and evaluated its effect on intertrochanteric hip fracture with finite element analysis. A three-dimensional model was made by using computed tomography images based on the data collected from a healthy volunteer. The fixation systems were constructed and registered with CAD. Two types of fixation system were defined (PFNA fixation system and improved PFNA fixation system). By using finite element analysis software, the boundary-constrained and load conditions were applied. Also the results (stress distribution and displacement) were analyzed. The average von mises stress distributions for femur decreased slightly (P>0.05) in improved PFNA group (7.33±1.77 MPa) compared with PFNA group (8.63±2.26 MPa), while the average displacement for femur decreased significantly (P<0.05) from 4.70±0.28 mm to 3.45±0.20 mm. The average von mises stress distributions for main nail increased slightly (P>0.05) in improved PFNA group (100.77±13.44 MPa) compared with PFNA group (99.26±12.96 MPa), while the average displacement for main nail decreased significantly (P<0.05) in improved PFNA group (2.78±0.97 mm) compared with PFNA group (3.82±1.34 mm). The maximum shearing strength on the tip of main nails also decreased from 10.3 MPa to 7.13 MPa. Therefore, we believe that the improved PFNA fixation system shows advantages for intertrochanteric hip fracture than PFNA fixation system.

Keywords: Biomechanical evaluation, intertrochanteric hip fracture, finite element analysis

Introduction

With the speeding up of population aging, intertrochanteric hip fracture in the elderly is increasing [1, 2]. Surgical treatment is becoming a prior option, for instance, the using of intramedullary nails attains good effects. PFNA (proximal femoral nail antirotation) has shown some advantages in treating intertrochanteric fractures. The PFNA decreases reverse displacement rates of the proximal screw and proximal femur [3, 4]. However, the varus angle of the proximal femur can not be completely eliminated by using PFNA. DHS (dynamic hip screw) can also be used for the treatment of intertrochanteric fractures but this method is not always successful, especially in unstable fractures [5]. Meanwhile, it was reported that 34% of secondary fracture displacement [6] occurred due to varus malunion or lag screw cutout. Subcapital femoral fracture, lag screw cutout and femoral shaft fractures were reported reaching a ratio 6%~19% [7] in DHS. Kaufer [8] reported that five independent variables effected the mechanical effectiveness of internal fixation after surgical treatment to intertrochanteric hip fracture, which were bone quality, fragment geometry, reduction, implant, and implant placement. Implant placement in the biomechanically ideal position was considered to be the most important of the 5 variables. So choosing the implant placement in the biomechanically ideal position seems crucial on the operative treatment of intertrochanteric hip fracture.

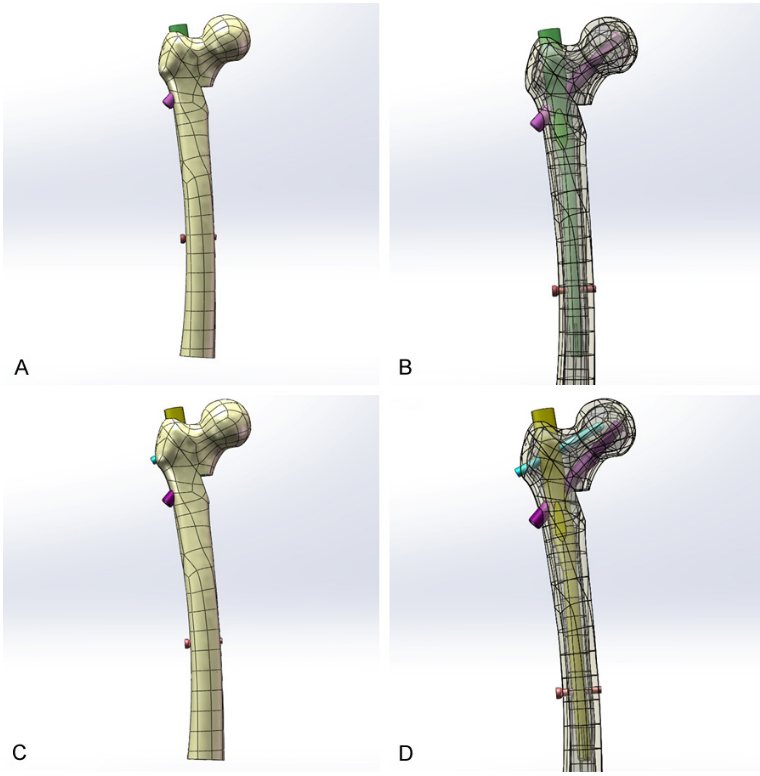

Figure 1. CAD models of intertrochanteric hip fracture with two types of fixation groups. (A, B) PFNA fixation group, (C, D) improved PFNA fixation group.

Table 1. Material property of different parts of the model

Material	Young's Modulus (MPa)	Poisson's ratio
Cortical bone	16800	0.30
Trabecular bone	840	0.20
Ti-6Al-7Nb	110000	0.33

Since finite-element-analysis (FEA) was first proposed by Brekelmans in orthopaedic biomechanics in 1972, FEA has been used to estimate the effects of operations and substitutions, and to predict behaviour under extreme conditions for forty-five years. Recently, FEA is widely used to estimate the effects of internal fixation for intertrochanteric hip fractures. Oken [9] et al used FEA to evaluate an modified anatomic plate (MAP) performs as well as the anatomic plate (AP), dynamic hip screw (DHS) and proximal femoral nail (PFNA) in trochanteric fracture, drawing a conclusion that the biomechanical features of the MAP were similar to those of the PFNA. Chen [10] studied the total hip arthroplasty following failed fixation of femoral intertrochanteric fractures by using a finite element analysis, concluding that an increase in the original stem length equal to the diameter of the femoral isthmus, or a distance between the most distal residual screw hole and the end of the femoral prosthesis, provide improved stress distribution.

In this study, we use the FEA method to build a new triangle fixation (improved PFNA) model aiming to cure Evans-II type intertrochanteric hip fracture. Also we evaluate the effect compared with the PFNA method.

Patient and methods

According with the national statement on ethical conduct in research involving humans, the research is authorized by the First Affiliated Hospital of Guangzhou University of Traditional Chinese Medicine. The femur involved in this research was obtained from an 60-year-old male volunteer (body weight, 60 kg; height, 170 cm) who was performed an CT scan based on relevant regulations of medical ethics under the supervision of the ethics committee. Before the research, an consent was obtained from the volunteer and the risks were reduced minimally. In a word, we promise that the research has no any ethical issues. In this study, the left leg of the volunteer was scaned by using a dual-source 64-slice spiral computed tomography to obtain a image. The slice thickness was 0.625 mm and the image matrix size was 512×512. After that, the image was processed with a online work station to obtain a digital imaging and communications (DICOM) format data file. The femur and the fixation devices were constructed by using a mimics 14.0 software. Next, the Evans-II type intertrochanteric hip fracture model was exported in "STL" format file. Two types of intertrochanteric hip fracture fixation models (PFNA fixation and improved PFNA fixation) were build using the FEA, as shown in **Figure 1A** and **1B**. The improved PFNA fixation is modified on the basis of the

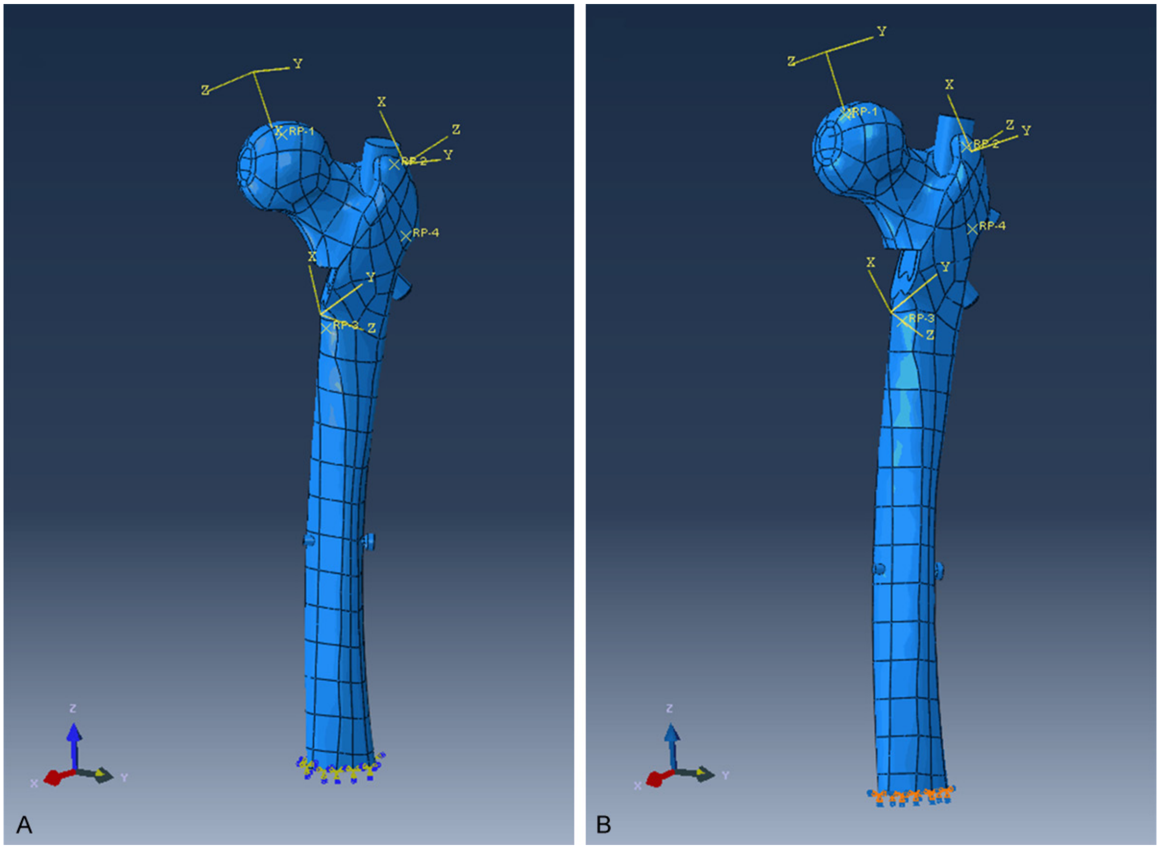

Figure 2. Boundary and load conditions of the two models. (A) PFNA fixation group, (B) improved PFNA fixation group.

Table 2. Values of four load cases

	Load case number	Applied vectorial forces/kN			Resultant
		x	y	z	
PFNA and Improved PFNA	1	0.616	-2.800	0.171	2.872
	2	-0.430	1.160	0	1.237
	3	0	-1.200	0	1.200
	4	-0.078	0.525	-0.560	0.771

PFNA fixation where the angel between neck nail and main nail is 145°. The angle between hollow nail and main nail is 110° according with the direction of weighted bone trabeculas which are used to resist compressive stress and tensile stress, respectively. The purpose of this method is also to rebuild the damaged bone trabeculas, and to remain the mechanical stability.

Mesh

The femur is consisted of cortical bone and cancellous bone. The material properties can be obtained from previous research data. The nails are assumed to be made of Ti-6Al-7Nb alloy [11-13] (elastic module $1.1{\times}10^5$ MPa) The poisson ratio is 0.33 as shown in **Table 1**. The materials are supposed as isotropic elastic metal materials with homogeneous microstructure. In addition, the three-dimensional models are ploted with 3-D 4-Node tetrahedral structural solid elements.

Boundary conditions and loading

To simulate the stance of giat, four load configuration are investigated as shown in **Figure 2**. **Table 2** lists the value of four load cases [14].

Statistical analysis

The one-way ANOVA method followed by post-hoc LSD multiple comparison is used to analyse the average Von Mises stress by using a SPSS 13.0 software. The P<0.05 is considered statistically significant.

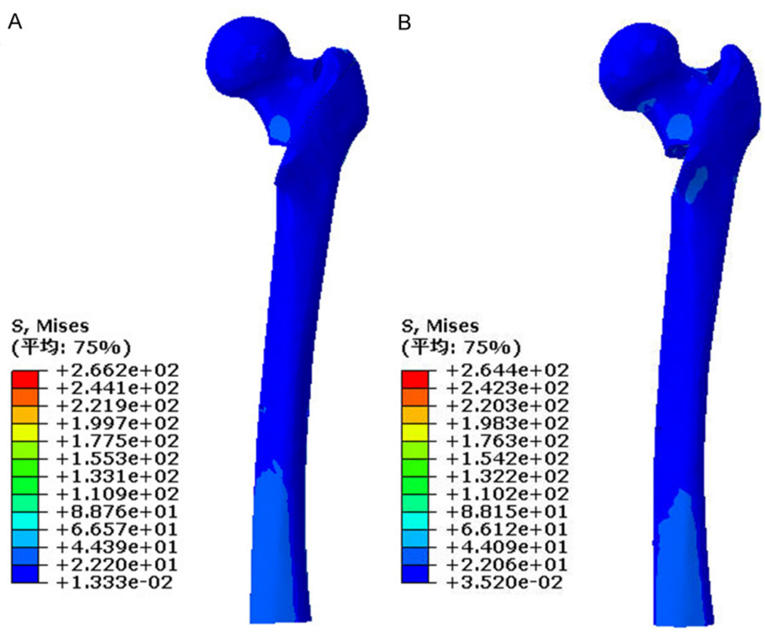

Figure 3. Von MisesStress distributions on femur in two types of fixation groups. (A) PFNA fixation group, (B) improved PFNA fixation group.

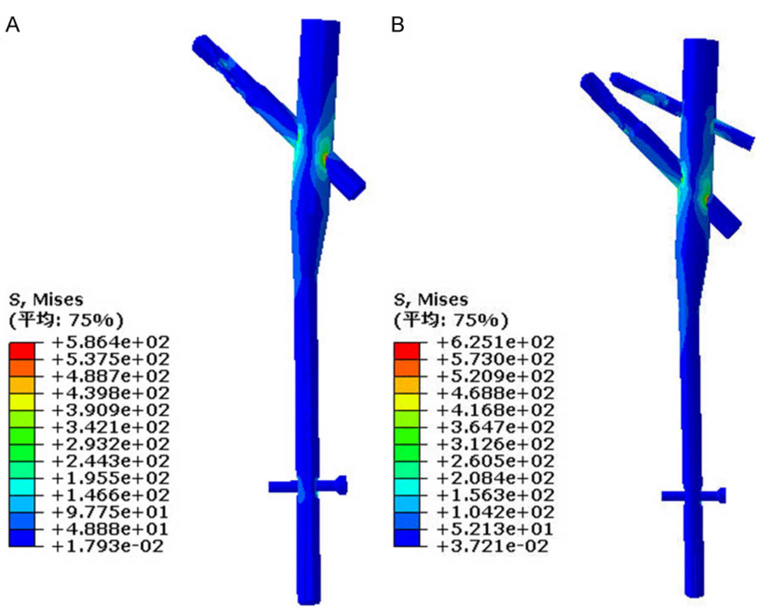

Figure 4. Von MisesStress distributions on nails in two types of fixation groups. (A) PFNA fixation group, (B) improved PFNA fixation group.

Result

Figure 3 shows the average Von Mises stress distributions of two types of fixation system. The average Von Mises stress distributions on femur for PFNA and improved PFNA fixation system are 8.63±2.26 MPa and 7.33±1.77 MPa, respectively. The average Von Mises stress distributions on nails are shown in **Figure 4**. The average Von Mises stress distributions on main nails for PFNA and improved PFNA fixation system are 99.26±12.96 MPa and 100.77±13.44 MPa, respectively. It can be seen that the main nail in improved PFNA group bears more stress which leads to a decreasing stress on femur.

The average femur displacement of PFNA fixation group and improved PFNA fixation group are 4.70±0.28 mm and 3.45±0.20 mm as shown in **Figure 5**. For main nails, the two values are 3.82±1.34 mm and 2.78±0.97 mm as shown in **Figure 6**. Both the displacements on femur and main nail decrease significantly in improved PFNA compared with PFNA group ($P< 0.05$).

In addition, we calculated the maximum shearing strength on the tip of main nails, the results were 10.3 MPa and 7.13 MPa for PFNA and improved PFNA fixation system, respectively.

Discussion

Currently, there are many fixation methods for intertrochanteric hip fracture, for example, the traditional PFNA fixation system [15-18]. However, the PFNA fixation system can not completely eliminate stress concentration due to the fact that the stress is largely applied on a point or a line. Hélin [19] reported that 6.7% assembly failures occured in 45 unstable fracture pattern patients who used PFNA fixation system. Li and co-authors [20] believed that "wedge-open" effect between head-neck and shaft by insertion of the cephalomedullary nail may be

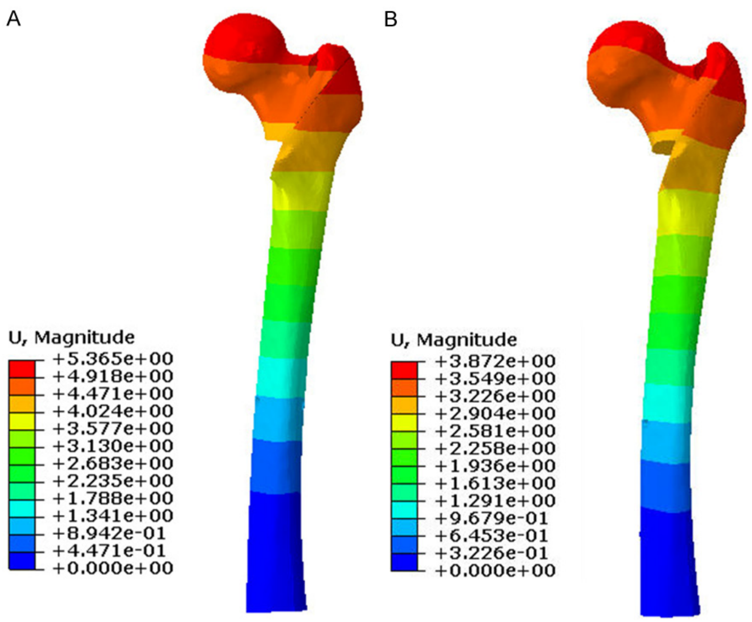

Figure 5. Displacement distributions on femur in two types of fixation groups. (A) PFNA fixation group, (B) improved PFNA fixation group.

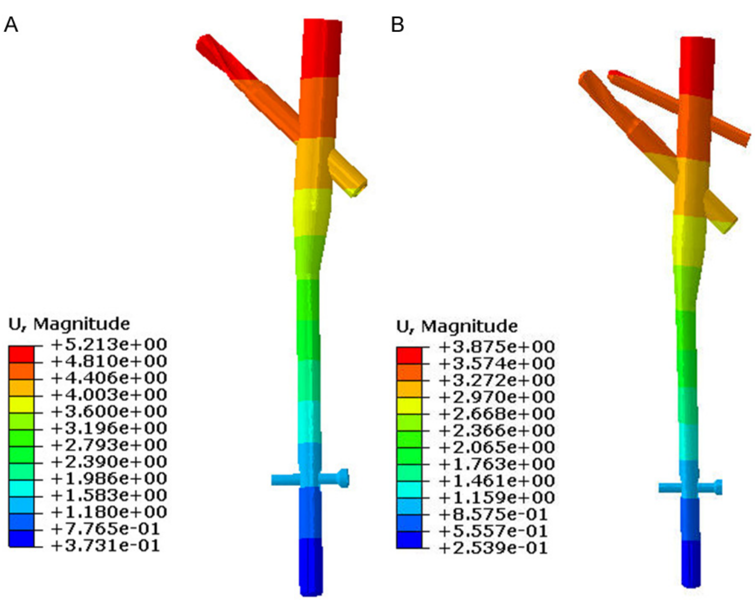

Figure 6. Displacement distributions on nails in two types of fixation groups. (A) PFNA fixation group, (B) improved PFNA fixation group.

the paramount reasons of early fracture impaction and blade cut-out. The purpose of this study was to evaluate the effect of an improved PFNA fixation system on intertrochanteric hip fracture, under the hypothesis that the femur is loaded. By building a triangular structure, the stress distribution transfers to a surface from a point and a line. Based on the large numbers of CT results we have done, we design a additional nail which has a 110 with the main nail. The nails are used to reconstruct the damaged trabecular bone. Through the improvement for intramedullary nails, the improved PFNA fixation system could obtain a more mechanical stability effect. The related results showed that the improved PFNA fixation system made the femur bear lesser stress, decreasing from 8.63 MPa to 7.33 MpPa. Meanwhile, the stress on main nails increased from 99.26 MPa to 100.77 MPa, indicating a favourable fixation effect. Besides that, the maximum shearing strength also decerased from 10.3 MPa to 7.13 MPa which indicated that the improved PFNA fixation system colud reduce local stress concentration. The improved PFNA fixation system decreased femur displacements and main nail displacements significantly. By this way, stress distribution transfers to nails from femur which could decrease some complications caused by shearing strength. The resules demonstrated that the improved PFNA fixation devices had good function. From the results we can know that the additional nail plays a positive role on keeping femur head stability by forming a new stress distribution area. This maneuver can produce a stable trigonal path and then prevent the shift and rotation of femur head, thus avoiding a early failure. However, this study was not considerate due to the neglect of soft tissue in the model. However, the materials and the tissues were hypothesized as homogeneous, continuous, and isotropic elastic, to some extent, the results can not reflect the true conditions. All the loads were applied in static conditions so the results can not describe the mechanical situation in dynamic conditions. Frankly speaking, these simulated results were obtained in vitro and the further effect in vivo still need to be tested in clinical.

Conclusion

The improved PFNA fixation devices gain better effect by using a finite element analysis reflected in decrease stress on femur and displacement in nails compared with the traditional PFNA fixation devices.

Acknowledgements

The authors would like to acknowledge the financial support from Technological Projects of Guangdong Province (No. 2014A030310379) and Technological Projects of Guangzhou (No. 1563000664).

Disclosure of conflict of interest

None.

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