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Biomechanical Study of Gamma 2 Intramedullary Nail, PFNA, and INTERTAN in the Treatment of Elderly Intertrochanteric Fractures of the Femur

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Abstract: ***A biomechanical comparison was conducted on the treatment of elderly intertrochanteric fracture models with Gamma 2 nail, PFNA, and INTERTAN using finite element method, providing a theoretical basis for the treatment of elderly intertrochanteric fractures. Construct a finite element model using numerical simulation to simulate the stress and strain mechanical distribution of the femur and intramedullary nails under axial loading after internal fixation of elderly intertrochanteric fractures. The peak stress-strain values in the intertrochanteric fracture area and intramedullary nail fixation under INTERTAN fixation are smaller than those in the other two fixation forms. Compared to intramedullary Gamma 2 nail and PFNA, INTERTAN has certain biomechanical advantages in treating elderly intertrochanteric fractures of the femur.***

Keywords: Finite element analysis; Intertrochanteric fracture; Intramedullary nail

1. Introduction

Intertrochanteric fracture of the femur is a common orthopedic disease in clinical practice, often occurring in the elderly. Studies have found that the mortality rate of elderly patients with intertrochanteric fractures of the femur is nearly 30%, while the one-year mortality rate of non-surgical treatment has significantly increased [1]. Therefore, surgical treatment has become the main method for treating elderly intertrochanteric fractures of the femur. Surgical methods are mainly divided into intramedullary fixation and extramedullary fixation. Biomechanical studies have shown that intramedullary fixation has more obvious advantages than extramedullary fixation [2]. In clinical practice, intramedullary fixation is gradually becoming the preferred method for treating elderly intertrochanteric fractures of the femur. With the continuous development of internal fixation forms and advances in biomechanical research, different structural forms of intramedullary nail systems have emerged. Among them, the proximal femoral interlocking intramedullary nail (Gamma2 nail), proximal femoral anti rotation intramedullary nail (PFNA), and INTERTAN intramedullary nail fixation systems are increasingly used in clinical practice.

Due to its ability to accurately and comprehensively describe the characteristics of bone under stress compared to traditional mechanical experiments, finite element analysis has gradually become an important method for studying the biomechanical properties of the femur, as it can well demonstrate the stress distribution, displacement, and overall trend of bone under different states. Starting from the perspective of finite element analysis, this article conducts a finite element study on the treatment of elderly intertrochanteric fractures of the femur with representative intramedullary Gamma 2 nails, PFNA, and INTERTAN systems in clinical practice, aiming to provide theoretical basis for clinical treatment.

2. Materials and Methods

2.1 Object model establishment

Construct a 3D data model of the fit between intramedullary nails and femur on software UG, as shown in Figure 1.

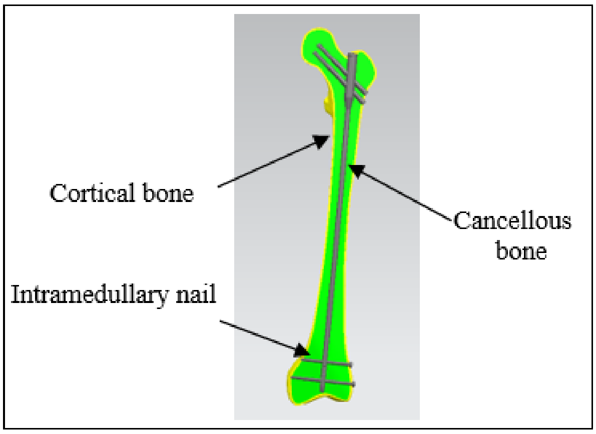


Figure 1: Intramedullary nail and femur assembly model

2.2 Finite element analysis material assignment

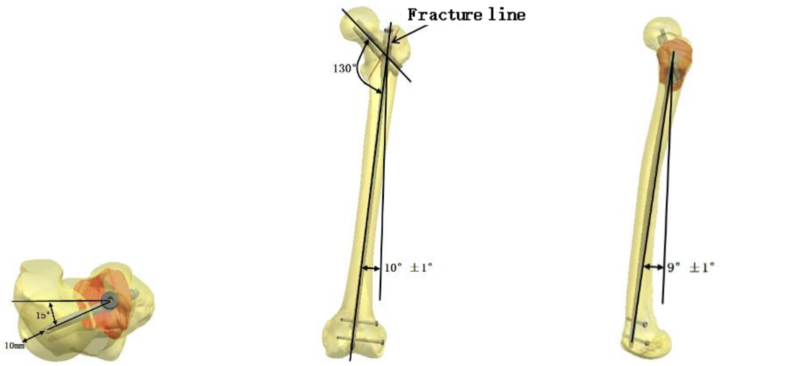
Import the 3D model constructed in UG into ANSYS Workbench. The material attribute assignment is shown in Table 1. TC4 material is selected for the main nail, locking nail, tension nail, spiral blade nail, and sealing cap. The bone is divided into cortical bone and cancellous bone. The analysis program uses the Static Structural analysis model.

Table 1: Material parameters

Material	*Elastic modulus (Pa)*	*Poisson's ratio*
TC4	1.1E+11	0.3
Cortical bone	0.24E+11	0.28
Cancellous bone	0.024E+11	0.2

2.3 Loading scheme

Simulate the force situation under axial loading after fixation of intertrochanteric fractures of the femur as shown in Figure 2. The intramedullary nail is fixed to the femoral neck according to a bone neck angle of 130 ° and a forward inclination angle of 15 °. The distance between the vertex of the tension nail or spiral blade nail and the vertex of the femoral head is set to 10mm for fixation. According to relevant literature, the reference value of human being height and weight is taken as the basic parameter of the human body model, which is a weight of 75kg. Bergmann et al. [4] found that the lower limb load is taken as the maximum joint resultant force that a person experiences at normal walking speed, which is approximately 2.6 to 2.8 times their body weight, and the axial compressive load on the femoral neck is set at 2300N.



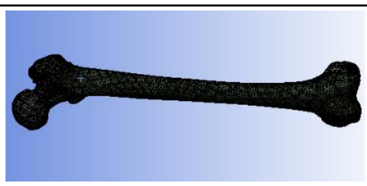
a) Cross section b) Coronal plane c) Disfigurement surface

Figure 2: Schematic diagram of intramedullary nails and femoral structure

2.4 Grid partitioning and constraints

To determine the optimal grid element size and ensure the authenticity and effectiveness of finite element analysis. Using Convergence for solving, set the Max Refinement Loops cycle value to 6 to determine convergence, and the Allowable Change criterion is within 5% convergence. The main nail, locking component, and bone model of the intramedullary nail were divided into tetrahedral and hexahedral grids. The femoral structure was divided into trabecular bone and cortical bone, and the hardness and density of cortical bone were both greater than those of trabecular bone. Therefore, hexahedral elements were used to simulate cortical bone, while tetrahedral elements were used to simulate trabecular bone, main nail, and locking component. The grid size converged steadily at around 2mm (with a grid spacing error of less than 5%). The main nail and locking component of the intramedullary nail, as well as the trabecular bone of the bone model, were meshed using tetrahedral mesh, while the cortical bone of the bone model was meshed using hexahedral mesh. The mesh size was set to 2mm to ensure sufficient computational accuracy. The mesh partitioning results are shown in Table 2.

Table 2: Grid partitioning results

Grid partitioning diagram	*Model structural form*	*Number of nodes*	*Number of grids*
	Gamma2 nail	226242	124430
	PFNA	202758	112083
	INTERTAN	234656	132376

Set the proximal end of the femur as the load surface, the distal end of the femur as the fixed constraint, set the connection between the fracture site as face to face contact, set the friction coefficient of the interface to 0.2 [5], and set the connection between the intramedullary nail and the femoral model as binding. In this simulation of intramedullary nail fixation of the femoral neck, there was no relative movement between the femoral shaft and the intramedullary nail in the axial mechanical analysis. The loading diagram is shown in Figure 3, which fully constrains all directional degrees of freedom between the femoral shaft and the intramedullary nail to 0.

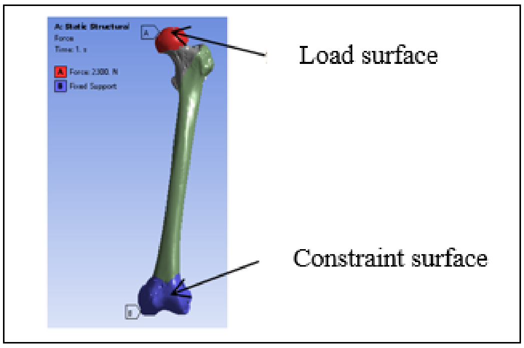


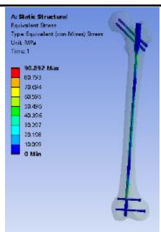
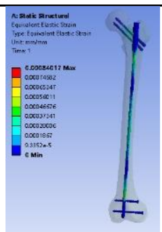
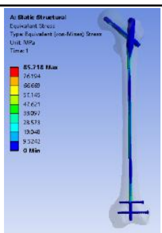
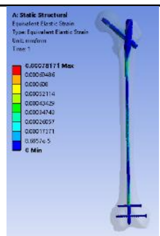
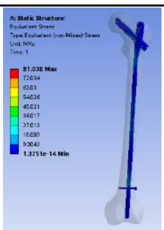
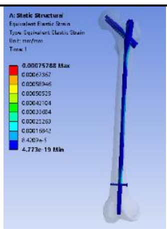
Figure 3: Load loading diagram

3. Result

3.1 Simulation results of intramedullary nails with different structural forms

The application results are shown in Table 3, which extract the equivalent force and equivalent strain values of different structural forms of intramedullary nails under axial loading. It can be seen that the equivalent stress and equivalent strain values of INTERTAN are smaller than those of other structural forms of intramedullary nails.

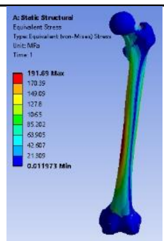
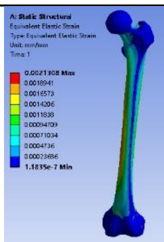
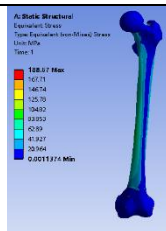
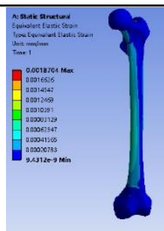
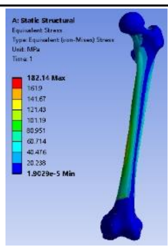
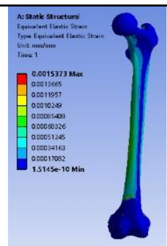
Table 3: Stress strain analysis results of different structural forms of intramedullary nails with equivalent effects

Structural form of intramedullary nails	*Equivalent stress (MPa)*	*Equivalent strain (mm/mm)*
Gamma2 nail	90.892	0.00084017
		
PFNA	85.718	0.00078171
		
INTERTAN	81.038	0.00075788
		

3.2 Simulation results of different structural forms of intramedullary nail fixation for repairing proximal femoral fractures

The application results are shown in Table 4, which extract the equivalent stress and equivalent strain values of different structural forms of intramedullary nail fixation for repairing intertrochanteric fractures of the femur under axial loading. It can be seen that the equivalent stress and equivalent strain values of INTERTAN fixed repair are smaller than those of other types of intramedullary nails.

Table 4: Equivalent stress-strain analysis results of different structural forms of intramedullary nail fixation for repairing proximal femoral fractures

Structural form of intramedullary nails	*Equivalent stress (MPa)*	*Equivalent strain (mm/mm)*
Gamma2 nail	191.69	0.0021308
		
PFNA	188.67	0.0018704
		
INTERTAN	182.14	0.0015373
		

4. Discuss

The intramedullary fixation system mainly consists of intramedullary main nails, tension screws, and distal anti rotation screws. With the enrichment of clinical experience and design improvements, the number of tension screws and rotation screws, as well as the structure of the main nail, have been improved. Gamma nails, proximal anti rotation intramedullary nails PFNA, InterTAN intramedullary nails, and other treatments have been introduced to treat intertrochanteric fractures of the femur.

Gamma nails have good rotational stability and the ability to resist shear forces of the femoral head by fixing two head and neck screws in a parallel or converging structure based on the stability after reduction and clinical needs on the combined interlocking intramedullary nail structure. When the head and neck screws adopt a converging interlocking structure, their rotational stability and angular stability are increased, which can avoid the Z-shaped effect and reduce the risk of intramedullary inversion and cutting out the femoral head. According to the theory of "triangular fixation" of the proximal femur [6], the fixation effect of 3 head and neck screws is greater than that of 2 head and neck screws and greater than that of a single head and neck screw.

In the design of head and neck screws, PFNA intramedullary nails use one spiral blade instead of two tension screws to avoid the Z-shaped effect of double screws. One internal implant is used to achieve anti rotation and stable support in the head and neck area. Not only does it avoid bone loss caused by drilling, but it also increases the contact area with the bone, improves local bone density, and enhances the stability of spiral blade fixation. The research results show that PFNA is superior to Gamma nail in terms of internal fixation failure rate, and has advantages such as less intraoperative bleeding and shorter hospital stay. [7-10]

The INTERTAN intramedullary nail is a combination of interlocking nails developed to address the original "Z" effect. The proximal cross-section of the main nail is trapezoidal, which can enhance the rotation stability of the main nail and improve its support for the lateral wall of the femur. Two screws are interlocked with each other to avoid the Z-shaped effect. Its research found that compared to PFNA, INTERTAN double head and neck screws have better stability and can better prevent the occurrence of femoral head rotation and intramedullary inversion. [11]

In this study, different structural forms of intramedullary nails were used to fix intertrochanteric fractures of the femur. Under the same axial loading conditions, the equivalent stress of the intramedullary nails was greater than that of other types of intramedullary nails, with values of Gamma 2 nail (90.892 MPa), PFNA (85.718 MPa), and INTERTAN (81.038 MPa) located at the junction of the main nail and the locking nail. According to relevant reports on medical titanium alloy materials, the yield strength of medical titanium alloys is usually not less than 700MPa [12]. Studies have shown that the peak stress of plants in both models is much lower than the yield strength, which can provide reliable fixation for fractures. And it was found that the analysis results were similar to the clinical application results, and the results were reliable.

The equivalent stress values of Gamma 2 nail (191.69 MPa), PFNA (188.67 MPa), and INTERTAN (182.14 MPa) under the same loading conditions after femoral fixation repair are all lower than the yield limit of human femoral cortical bone, which is 240.32 MPa [13]. From this, it can be seen that the Gamma 2 nail fixation results in the highest equivalent stress in the proximal femur and stable medial support. Strain refers to the relative deformation of an object that occurs locally under the influence of external forces and other factors. It is the ratio of the deformation variable to its original size ε Representation, $\varepsilon = \Delta L/L$ [14]. The research results show that the equivalent strain values after femoral fixation are Gamma 2 nail (2130.8 × 10-6), PFNA (1870.4x10-6), and INTERTAN (1537.3 x10-6), all located at the proximal medial end of the femur. According to Frost's theory [15], when strain (ε) reaching 3000 x10-6, excessive bone micro damage will occur, leading to trabecular fracture and fatigue fracture of the bone. From the research, it can be seen that the peak strain of both models did not reach the threshold that can cause stress fractures of the femur. This can provide a theoretical basis for further clinical application.

In summary, Gamma2 nails, PFNA, and INTERTAN can all be used for the treatment of intertrochanteric fractures in the elderly. Compared to Gamma2 nails and PFNA, INTERTAN has certain biomechanical advantages.

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