

# Finite Element Analysis of the Optimal Configuration of Bridging Combined Internal Fixation System in The Treatment of Vancouver B1 Periprosthetic Femoral Fractures

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## Research

**Keywords:** Periprosthetic femoral fracture (PFF), Bridged combined internal fixation system (Ortho-bridge System, OBS), Finite element analysis (FEA).

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# Abstract

**Background and Objective:** The incidence of periprosthetic fracture increases with the increase of total hip arthroplasty. The treatment of periprosthetic fracture is always a difficult point. The bridged combined internal fixation system (Ortho-bridge System, OBS) is well adapted to the characteristics of periprosthetic fractures. In this study, finite element analysis was used to evaluate the optimal configuration of OBS for fixation of Vancouver B1 periprosthetic femoral fractures.

**Methods:** A three-rod combination OBS fixation model was established to evaluate the optimal position of the third rod, the cross Angle of proximal screws, the diameter of the connecting rod, and the number of screws. Femoral displacement and the maximum Von Mises (equivalent) stress of OBS were used as evaluation indexes.

**Results:** The third rod is located at 35mm below the lateral fovea of the femur and the minimum Von Mises peak stress of OBS, which is the best location for placing the third rod. It is feasible for proximal screw intersection Angle to be about  $71^\circ$  and  $84^\circ$ . To fix the strength, the 6mm connecting rod is better. Considering the number of screws scheme comprehensively, scheme D is the best number of screws scheme.

**Conclusion:** The personalized and diversified fixation mode of OBS is well adapted to the characteristics of periprosthetic fracture and provides an effective means for the treatment of periprosthetic femoral fracture.

## Introduction

As life expectancy increases, the incidence of falls and osteoporosis increases year by year. At the same time, the improvement of people's requirements for quality of life and the progress of surgical technology makes the application of hip arthroplasty more and more. As a result, Total hip arthroplasty (THA) demand is expected to increase by 174% to 572,000 procedures by 2030<sup>1</sup>. Unfortunately, there has been an increase in post-THA problems, including Periprosthetic fracture (PPF)<sup>2</sup>. Abdel M P et al. reviewed 32,644 patients undergoing primary total hip arthroplasty and found that the incidence of intraoperative femoral fractures was 1.7% and that postoperative periprosthetic fracture was 3.5%<sup>3</sup>. A prediction model shows that the number of periprosthetic fractures will increase by an average of 4.6% per decade from 2015 to 2060<sup>4</sup>, with a high clinical and economic burden<sup>5</sup>.

Treatment of periprosthetic fractures is complex due to the presence of artificial hip prostheses and the poor essential physical condition of patients with periprosthetic fractures<sup>6</sup>. The treatment is varied. Accurate classification is significant for managing periprosthetic fractures of the artificial hip, and the Vancouver classification is currently the most commonly used<sup>7</sup>. Vancouver type B1 fracture is a stable prosthetic fracture with no loss of bone mass and is treated with internal fixation as the preferred treatment<sup>8-10</sup>. Tanvir Khan reviewed 6,131 patients with PPF and found a high risk of death, with a 5-year

mortality rate of 60% in the highest risk group<sup>11</sup>. The plate series is the standard treatment method, which can be combined with the ring ligation, and has achieved a particular effect<sup>12-15</sup>. The advantages of using a locking compression plate in the treatment of periprosthetic fractures are direct exposure and reduction of the fracture. The disadvantages are soft tissue dissection and the difficulty of obtaining bicortical screw fixation due to intramedullary prosthesis occlusion. Locking compression plate can be combined with Minimally invasive plate osteosynthesis (MIPO) to treat periprosthetic fractures and maintain bone vitality<sup>16</sup>. Some scholars suggest additional methods such as allogeneic bone plates and fixation of at least 10 cortices<sup>17-20</sup>. The most common complications of existing internal fixation methods included fixation failure and nonunion, with rates of 4.4% and 3.9%, respectively<sup>21</sup>.

The bridged combined internal fixation system(Ortho-bridge System, OBS) is a composite structure composed of the fixed block, fixed rod, and screw. The selected blocks include single side single hole, single side double hole, double rod single hole, double rod double hole, and special-shaped blocks adapted to different anatomical positions; Fixed rod includes unequal diameter; The screws include locking screws and standard screws (see Fig. 1). Its design concept advocates individualization, diversification and systematization of orthopedic internal fixation, with the advantages of individualized shaping, free combination, three-dimensional fixation, elastic fixation, etc. In this study, the biomechanical properties of different varieties of bridging combined internal fixation systems in the treatment of periprosthetic fractures were analyzed by finite element analysis to determine the optimal configuration of nails, rods, and blocks.

## Results

### Verification of scheme validity

The same bone condition was used to simulate a femoral shaft fracture at the same site, and fixation was performed with a plate (see Fig. 2). The comparison results with OBS are shown in Table 1. In OBS treatment of periprosthetic fractures, the stress at the fracture end was lower than that of simple femoral shaft fractures fixed with steel plate, which proved that the fixation was effective.

Table 1  
Verification of scheme validity

	OBS	plate
femoral displacement (mm)	13.37	24.88
maximum Von Mises stress of OBS (MPa)	1141.70	2258.40

### Optimal third rod position

The analysis results were shown in Table 2. With the downward movement of the third rod, the femoral displacement generally showed a decreasing trend, while the maximum Von Mises stress of OBS showed

an increasing trend. Thus, the comprehensive analysis showed that the femoral displacement and the maximum Von Mises stress of OBS were the minimum at the downward movement of the third rod 35mm.

Table 2

Relationship between femoral displacement, the maximum Von Mises stress of OBS and the position of the third rod

	0mm	10mm	20mm	25mm	30mm	35mm	50mm
femoral displacement (mm)	15.28	15.23	16.71	15.09	15.12	14.42	14.51
maximum Von Mises stress of OBS (MPa)	771.77	786.47	1088.70	842.96	844.45	814.70	854.91

## Optimal cross Angle of proximal screw

The analysis results were shown in Fig. 3. When the spatial Angle between the proximal third rod screw and the first and second rod fixation screws was  $71.92^\circ$ , the femoral displacement and the maximum Von Mises stress of OBS were the minimum in the comprehensive analysis.

## Optimal connection rod diameter

The results are shown in Table 3. Femoral displacement and the maximum Von Mises stress of OBS are both smaller when using a 6mm diameter connecting rod than when using a 5mm connecting rod.

Table 3

Relationship between femoral displacement, the maximum Von Mises stress of OBS and connection rod diameter

	5mm	6mm
femoral displacement (mm)	13.73	11.85
the maximum Von Mises stress of OBS (MPa)	1141.70	817.20

## Optimum screws number scheme

The results were shown in Table 4. Again, scheme F had the most significant number of screws, and both femoral displacement and the maximum Von Mises stress of OBS were the smallest.

Table 4

Relationship between femoral displacement, the maximum Von Mises stress of OBS and screws number scheme

	a	b	c	d	e	f
femoral displacement (mm)	12.38	21.08	13.26	13.37	12.36	11.61
the maximum Von Mises stress of OBS (MPa)	740.17	813.02	901.20	712.59	1088.90	701.71

## Discussion

There are various methods of internal fixation for fractures around the Vancouver type B1 prosthesis. Still, due to the presence of the intramedullary prosthesis, the double cortical fixation cannot be achieved, the holding power of the internal fixation is reduced, and the conventional internal fixation often fails to achieve a strong fixation, leading to reoperation<sup>19,22</sup>. The unique locking structure of OBS consists of a pin, rod, and block, which are freely matched to form a plurality of internal fixation complexes. Different from the single position and direction of plate series screws, the position and direction of OBS screws can be adjusted and controlled at will according to the situation, providing wider operability and applicability for the treatment of periprosthetic fractures and well making up for the shortcomings of other internal fixation devices. The multi-rod fixation mode and cross-screw fixation of OBS can achieve three-dimensional fixation and further improve the fixation strength. The rod-block combination can better disperse stress, avoid stress concentration and reduce the fracture risk of the internal fixator<sup>23</sup>. In addition, intraoperative soft tissue dissection is too much; the blood supply is reduced and can easily make the fracture heal. Therefore, the application of OBS can achieve minimally invasive or limited incision operation, with minimal damage to soft tissue and periosteum. Bridging fixation does not directly compress the periosteum and fracture site, which has little impact on the blood supply of the fracture area and protects the biological environment of the fracture area<sup>24</sup>. An animal experiment also showed that OBS could effectively reduce the disruption of blood supply at the fracture site and provide a firm fixation<sup>25</sup>. The OBS connection block can slide axially to achieve compression and has the function of a "reset device," which can be fixed by changing the reduction edge during surgical operation<sup>26</sup>.

The use of OBS in the treatment of Vancouver B1 periprosthetic fracture of the femur has been proven to be solid and reliable with satisfactory clinical results<sup>27</sup>. Due to the flexibility of the OBS combination mode, this experiment was designed to explore the optimal combination mode. The OBS rod-block structure allows the screw position to be adjusted freely according to the specific situation, and the pressure hole or lock hole can be selected freely. The angular screws have better pull-out resistance and fixed strength<sup>15</sup>. The three-dimensional fixation of OBS can be achieved well when the three-rod fixation is used. The third rod is about 20mm below the lateral concave of the femur, and the femoral displacement and the maximum Von Mises stress of OBS are both the maximum. The failure possibility of internal fixation is the highest when the third rod is placed there. The lower 35mm femoral deformation

and OBS stress are minimal, which is the best third-rod placement position. The intersection Angle of the proximal screw on the femoral displacement and the maximum Von Mises stress of OBS is generally gentle. Still, there are two trough points; namely, the intersection Angle is about  $71^\circ$  and  $84^\circ$ , respectively. We believe that both of these two cases are feasible. To fix the strength, it is recommended to choose a 6mm connecting rod with low femoral displacement and the maximum Von Mises stress of OBS. Although the number of screws was the most stable, considering the complexity of the clinical operation, we believed that the plan D with little difference was the best plan for the number of screws.

Our study has its limitations. The study included subjects that did not reflect actual bone mass in patients with periprosthetic fractures. In addition, due to the stress shielding effect, the proximal femur bone mineral density will decrease, and the Gruen7 area has the greatest decrease<sup>28,29</sup>. However, bone loss was not considered in this experiment. Muscle and other soft tissues were not considered in this study, and only biomechanical evaluation under the same bone and the same load was performed.

## Conclusion

The personalized and diversified fixation mode of OBS is well adapted to the characteristics of periprosthetic fracture and provides an effective means for the treatment of periprosthetic femoral fracture.

## Methods

### Finite element model establishment

The bone model was derived from a 48-year-old healthy male volunteer whose CT data were collected. He had no skeletal lesions, no previous surgery history, no tumor history, and no drugs affecting bone metabolism in recent years. According to the size parameters of the femoral prosthesis and OBS, the three-dimensional models of the femoral prosthesis and OBS were established and assembled, and the fracture line was simulated at the distal end of the femoral prosthesis stem (see Fig. 4). For the material properties of cortical bone, elastic modulus  $E_x = E_y = 7.00\text{GPa}$ ,  $E_z = 11.50\text{GPa}$ , shear modulus  $G_{xy} = 2.60\text{GPa}$ ,  $G_{yz} = G_{xz} = 3.50\text{GPa}$ , and Poisson's ratio was 0.4. The elastic modulus of cancellous bone was  $0.40\text{GPa}$ , and the Poisson's ratio was 0.3. The femoral stem, connecting rod, and screw were made of titanium alloy with an elastic modulus of  $110.00\text{GPa}$  and a Poisson's ratio of 0.3. The connecting block comprises cobalt-chromium molybdenum alloy with an elastic modulus of  $210.00\text{GPa}$  and a Poisson's ratio of 0.3<sup>30</sup>. Tetrahedral 10-node units were used to mesh the above structures. The mesh size of cortical bone was 3mm, the mesh size of cancellous bone and the femoral stalk was 2mm, and the mesh size of connecting rods, screws, and connecting blocks was 1.5mm. There were 249,285 mesh units and 390,122 nodes in total. The binding contract between the screw and cortical bone, screw and joint block, joint block and rod, and femoral stem and bone was set, and there was no frictional contact between the broken ends of the fracture. A force of  $F_x = 300\text{N}$ ,  $F_z = -600\text{N}$  was applied to the top of the femoral head

and the distal femur was fixed with 6 degrees of freedom set to 0. The evaluation criteria included femoral displacement and the maximum Von Mises (equivalent) stress of OBS.

## Optimal three-rod position relationship

The arc of the third rod was assembled near the great trochanter. Then, starting from the lateral recess of the femur, the mechanical properties of the third rod moving down 0mm, 10mm, 20mm, 25mm, 30mm, 35mm, and 50mm were analyzed, respectively, and the optimal position of the third rod was analyzed (see Fig. 5).

## Optimal cross Angle of proximal screw

According to the optimal position of the third rod and the flexibility of the proximal connecting block (B) of the third rod, the direction of the proximal screw was adjusted accordingly. According to the position in Fig. 6, the optimal intersection Angle of the proximal screw was analyzed by gradient analysis at a spatial Angle of 3°.

## Optimal diameter of connecting rod

OBS connecting rod has two specifications: 5mm and 6mm. Two fixing models of connecting rods are used respectively to analyze the optimal diameter of connecting rod.

## Optimal screw number scheme

According to the optimal position of the third rod and the optimal intersection Angle of proximal screws analyzed in the previous two steps, the fixation model with the different number of screws was used to analyze the optimal number of screws. (Fig. 7)

## Declarations

Ethical Approval: Approved by Yan'an Hospital Affiliated to Kunming Medical University Ethical Committee.

**Conflict of interest statement :** We declare that we have no financial and personal relationships with other people or organizations that can inappropriately influence our work, there is no professional or other personal interest of any nature or kind in any product, service or company that could be construed as influencing the position presented in the manuscript entitled "Finite element analysis of the optimal configuration of bridging combined internal fixation system in the treatment of Vancouver B1 periprosthetic femoral fractures".

**Data Availability :** The data sets used and analyzed during the current study are available from the corresponding author on reasonable request.

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**Author's Contribution :** Long Zhang, Md Ariful Haque : substantial contributions to conception, design and writing.

Ying Xiong, Jing Qin, Luyun Liu, Yingjie Zhang : data acquisition and interpretation.

All Author : critically revising it for intellectual content and final approval of the version to be published.

Jiayu Xiao and Ying Xiong : agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of the work are appropriately investigated and resolved.

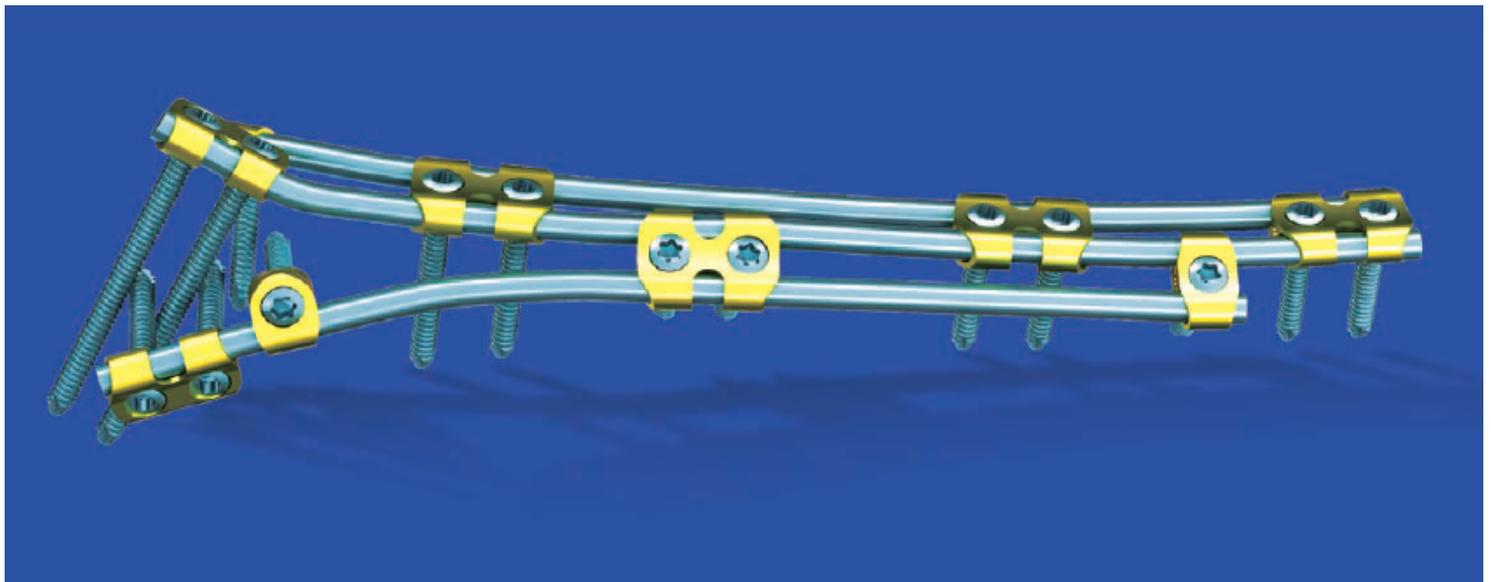
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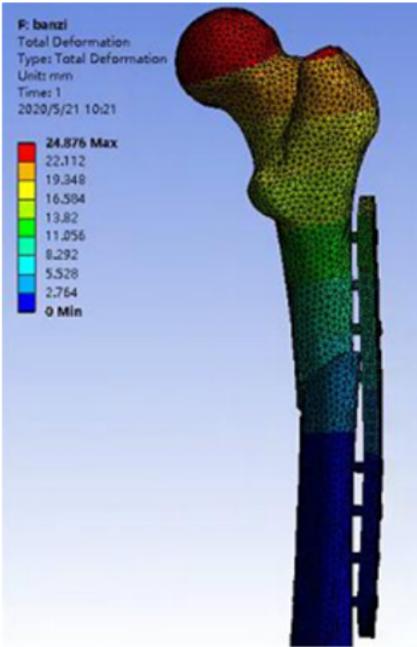
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## Figures

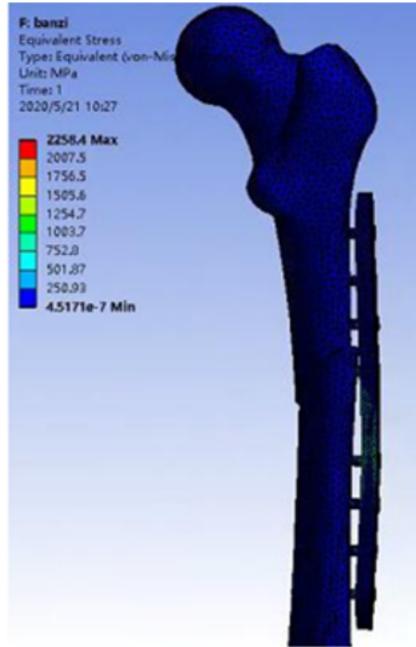


**Figure 1**

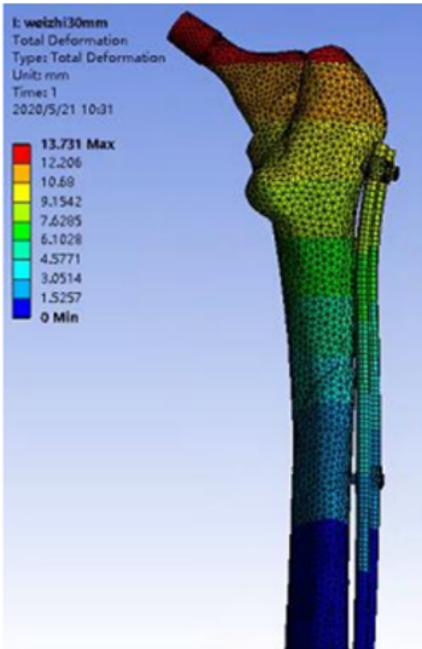
Bridged combined internal fixation system (Ortho-bridge System, OBS)



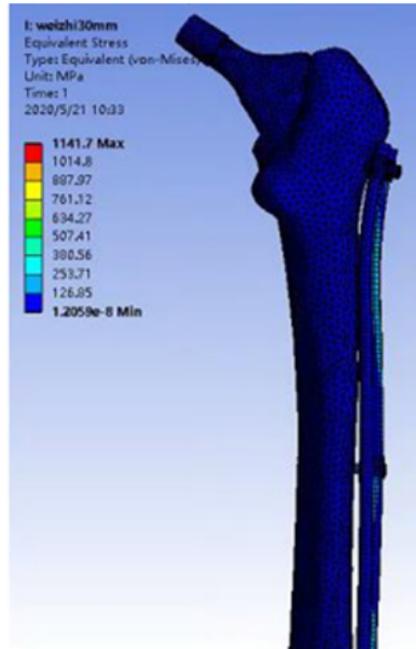
(a)



(b)



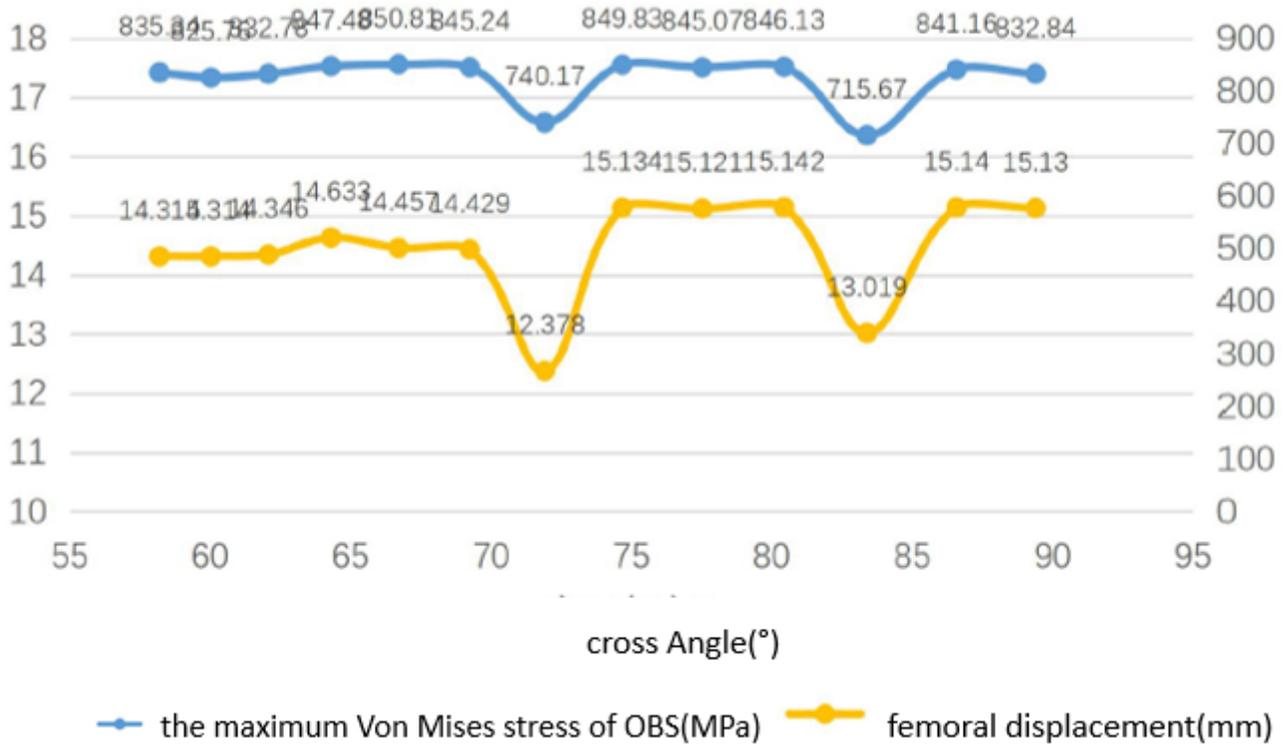
(c)



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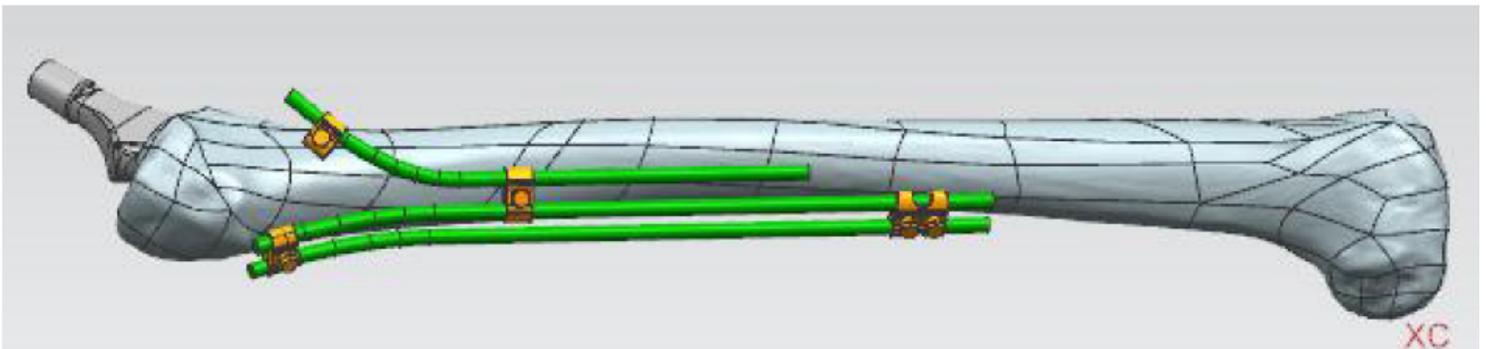
**Figure 2**

Verification of scheme validity(a: femoral displacement fixed by steel plate, b: stress distribution diagram for steel plate fixation, c: femoral displacement fixed by OBS, d: Stress distribution diagram for OBS fixation)



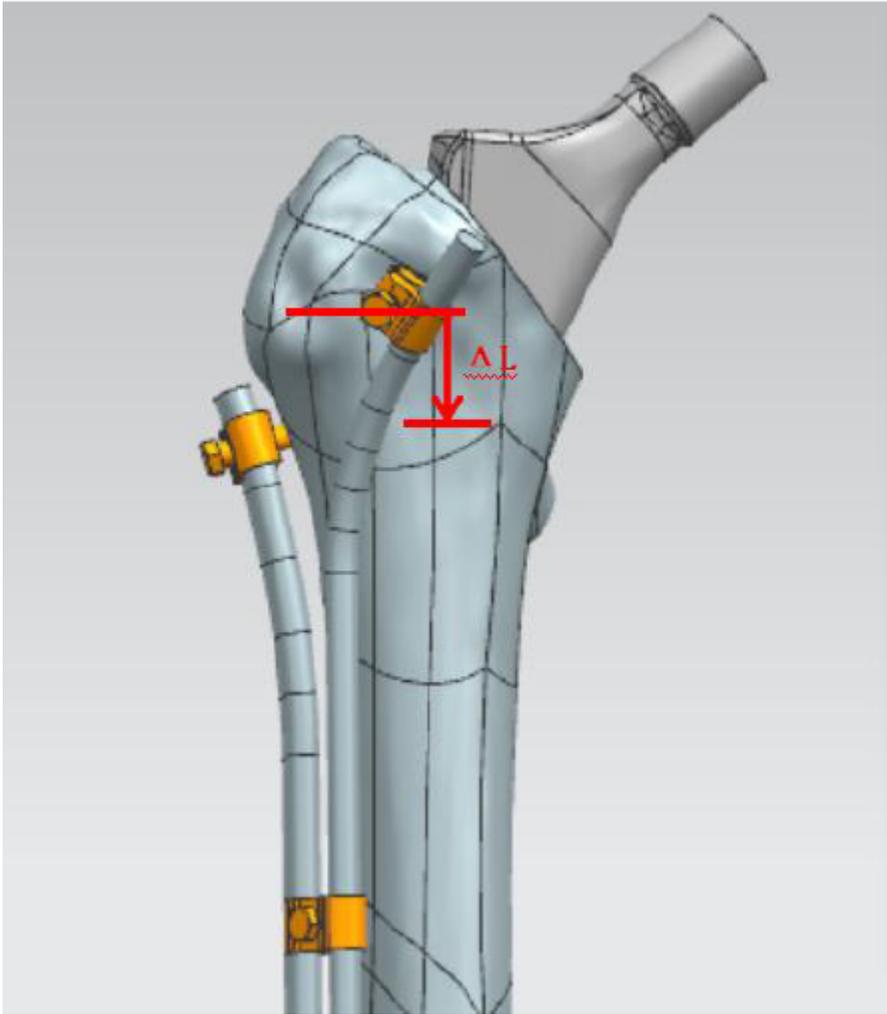
**Figure 3**

Relationship between femoral displacement, the maximum Von Mises stress of OBS and cross Angle of proximal screw



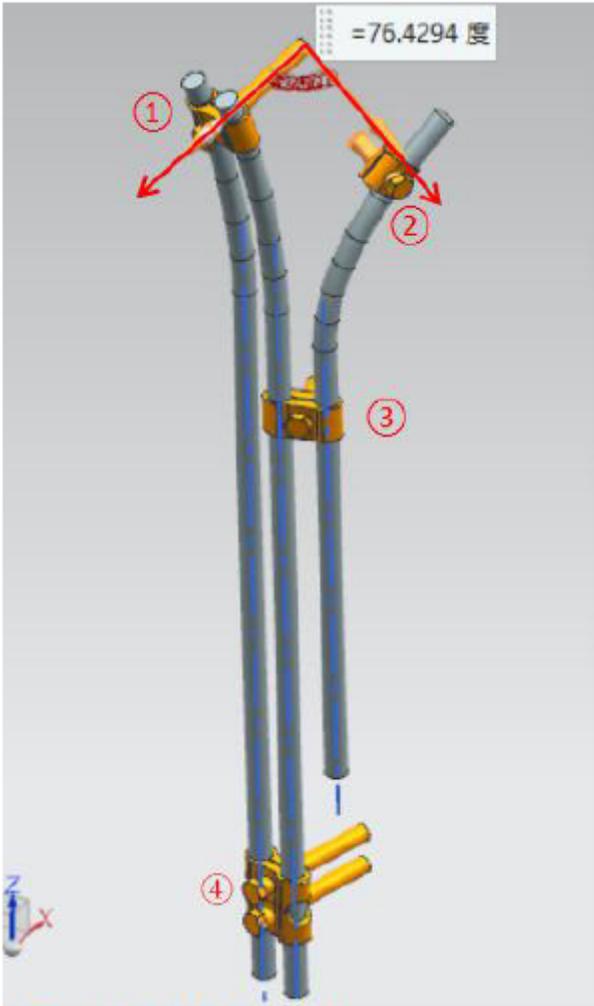
**Figure 4**

Periprosthetic femoral fracture model with OBS fixation



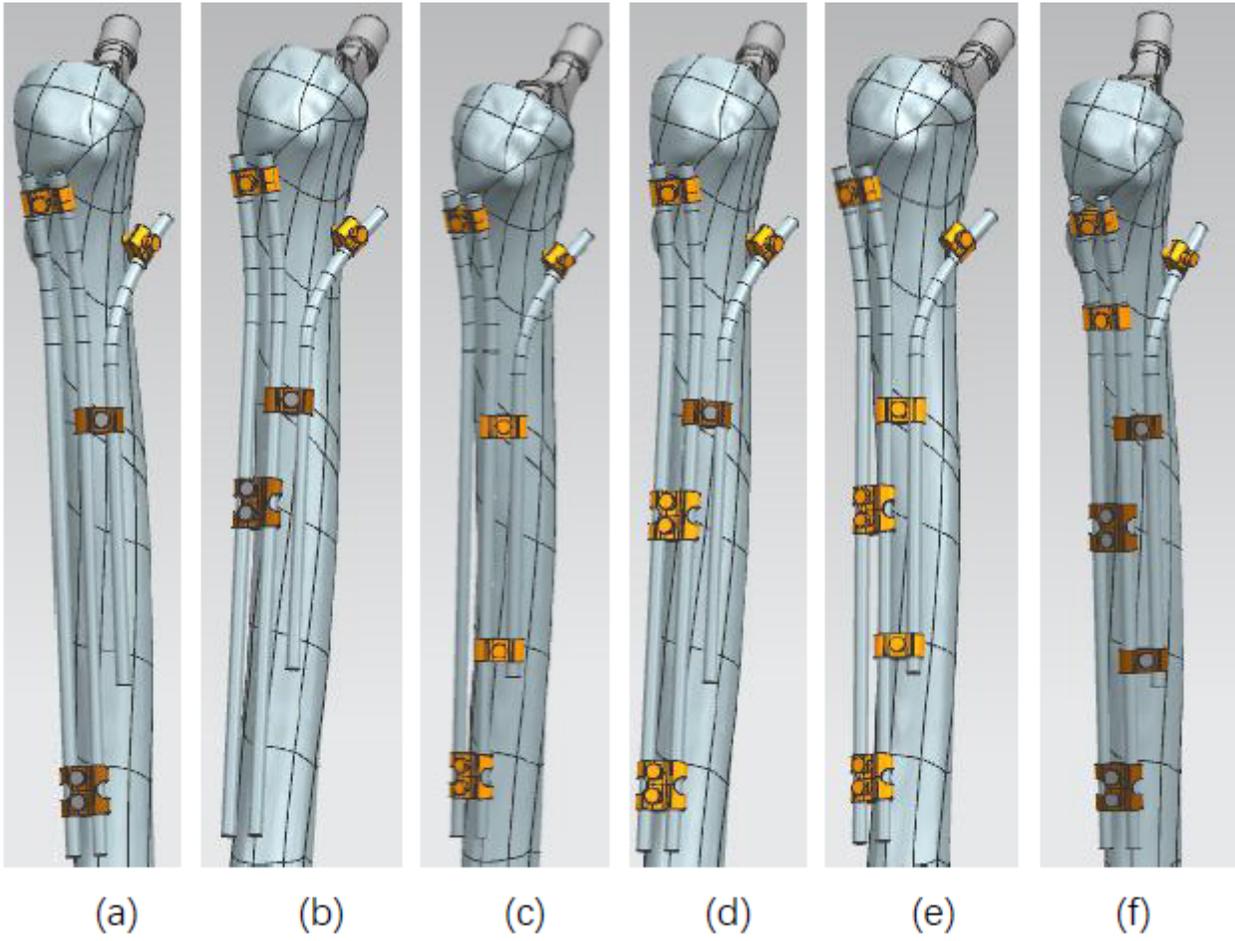
**Figure 5**

Position design of the third rod



**Figure 6**

Cross Angle of proximal screw



**Figure 7**

screw number scheme