Research on Biomechanical Application of Fracture Reduction Fixator Based on Finite Element Analysis

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Abstract. This article uses CAXA 3D solid design software to model the fracture reduction fixator, and assemble the model according to the requirements of clinical medicine. Obviously apply 50N, 100N, 150N, 200N axial load to the model, and obtain the relationship between axial load force and displacement. The stiffness of the model calculated by SPSS23.0 statistical analysis software is 88.5N/mm. The stiffness of the fracture reducer measured by the biomechanical model was 85.4N/mm, and the ratio between the two was 1.037, which was within the error range. Prove that the model and calculation method established in this study can provide reference for clinical medicine.

Keywords: finite element analysis; fracture reduction fixator; biomechanics; three-dimensional modeling

1. Introduction

The current fracture treatment theory is still at the basic stage, that is, relying on specimen experiments to find ways to reduce the stress interference at the fracture site to promote fracture healing. However, the models or specimens used in traditional specimen experiments are different from the human bones, and the experimental equipment and the technical level of the experimenters are only at the basic stage, so the conclusions obtained cannot be used well in clinical medicine. In order to provide better treatment options, many domestic experts and scholars have also proposed various research directions. [1-2] For example, You Xiaojun (2019) studied the application of external fixation stents in extremity fractures; Qi Xin (2020) discusses fracture treatment from the perspective of ring external fixation technology.[3-5]

In order to further explore the time-dependent biomechanical characteristics of fracture treatment, this paper proposes a biomechanical application study of fracture reduction fixator based on finite element analysis. Finite element is a widely used engineering research mechanics method. [6] Many scholars are slowly trying to introduce finite element analysis into medical correction, such as in vitro biomechanical testing and finite element analysis of the domestically-made new lumbar interspinous process spreader. In this study, a three-dimensional finite element model and calculation method were established to try to simulate the characteristics of bone mechanics in vivo, and the effectiveness of the
method was verified by comparison with traditional physical mechanics model experiments.

2. Based on finite element fracture reduction fixator three-dimensional model establishment and calculation

2.1. 3D model establishment
In order to make the model fit the reality better, the three-dimensional model of the fracture reduction fixator structure established in this study was constructed 1:1 using CAXA 3D solid design 2015 software. The modeling method is: in the CAXA 3D solid design software, the fracture reduction fixator that meets the clinical reality is assembled. Assembly requirements: the distance between the support rod and the distal fixed needle is 29mm; the distance between the support rod and the proximal fixed needle is 25mm; the distance between the proximal half ring and the distal half ring is 275mm. After the modeling is completed, export it according to the STEPAP214 (*stp*step) file format. The established three-dimensional model is shown in Figure 1.

![Figure 1. Three-dimensional model of fracture reduction fixator](image)

2.2. Meshing
After completing the establishment of the 3D model, import the exported file into the MSC.Marc finite element analysis software to perform tetrahedral meshing. After the file is meshed, 23623 nodes and 160916 elements can be obtained.

2.3. Material property setting
In order to avoid errors caused by material properties, the materials involved in this experiment are set to be homogeneous, isotropic, and continuous. In order to make the data more accurate, the Young's model of stainless steel is set to 193000Mpa and the Song Poise ratio is 0.31.

2.4. Load settings and boundary conditions
In order to determine the load setting of the three-dimensional model, the other parts of the model are set as a fixed connection, and the degree of freedom in the three-dimensional space of the proximal half ring and the bottom parts of the two support rods is 0. A downward force of 50N, 100N, 150N, 200N is applied in the Z direction of the log center respectively.

3. Physical mechanics experiment of fracture reduction fixator

3.1. Experiment preparation
The experimental materials are shown in Table 1.

| Device name                  | WD-I        | Complete fracture reduction | SSW Proximal half ring-- | SSW Distal half ring-- | SSW Needle lock | SSW Support rod--350 |
|-----------------------------|-------------|-----------------------------|--------------------------|------------------------|-----------------|----------------------|

Table 1. Experimental materials of physical mechanics
3.2. Axial loading experiment

3.2.1 Preparation for axial loading experiment

Before the axial experiment, the fracture reduction fixator needs to be installed. Drill a ψ2.8mm hole at the center of the sides of the two round wooden rods so that the drilling direction is perpendicular to the long axis of the wooden rod and passes through the axis. Knock the prepared bone round needles into the holes of the two round wooden rods, and fix them with 502 glue to avoid the sliding of the bone round needles and cause the experiment to fail. After completing the above steps, the fracture reduction fixator is installed according to the finite element three-dimensional model, and the various parts of the fracture fixator are tightened as required.

3.2.2 Axial loading experiment process

First use 2kg and 4kg weights to calibrate the loading value of the WD-I electronic universal testing machine, and record the loading values of 2kg, 4kg and hour respectively to obtain the sensor force-voltage proportional coefficient, which is used to calculate the loading Force value. Fix the proximal half ring of the fracture reduction fixator and the proximal end of the support rod at the bottom of the WD-I electronic universal testing machine. At this time, the log at the bottom of the fracture reduction fixator is suspended. Load at the center of the log perpendicular to the downward direction of the bone needle at a speed of 2mm/min, and record the voltage reading on the measuring and control instrument of the testing machine when the loading time is 15s, 30s, 45s, 60s, and repeat the above steps 5 times. The assembly of the fracture reduction fixator is shown in Figure 2.
4. Experimental results

4.1. Results of finite element analysis of fracture reduction fixator

When the fracture reduction fixator is loaded with a downward force of 50N, 100N, 150N, 200N in the Z direction of the log center, the finite element results can be calculated according to the displacement of the log in the Z direction. When the axial loading force is 50N, the displacement is 0.584mm; the axial loading force is 100N, and the displacement is 1.117mm; the axial loading force is 150N, and the displacement is 1.675mm; the axial loading force is 200N, and the displacement is 2.233. In order to make the results more intuitive and accurate, the relationship between axial loading force and displacement is drawn as a scatter diagram, as shown in Figure 3.

![Figure 3. Scatter diagram of the relationship between axial loading force and displacement calculated by finite element](image)

It can be seen from Figure 3 that in the finite element experiment, the axial loading force has a linear relationship with the displacement. In order to further explore the relationship between axial loading force and displacement, SPSS22.0 statistical analysis software is used to fit the relationship between axial loading force and displacement, and the variance analysis of the curve is calculated, and the significance analysis of the regression coefficient is carried out. Statistics of the analysis results are shown in Table 2. From Table 2, it can be seen that the curve fit is 1, and the P value of the regression coefficient significance analysis and curve analysis of variance is less than 0.05.

| Curve fitting | Goodness of fit | P | Coefficient $\beta_1$ | P | Constant ($\beta_2$) |
|---------------|----------------|---|-----------------------|---|---------------------|
| Linear curve  | 1              | 0.00 | 0.011 | 0.000 | 0.026 |

At this time, it can be determined that the axial loading force and displacement of the fracture reduction fixator are linear. The displacement formula can be determined from this result as:

\[
\text{Displacement}=0.011\times\text{axial loading force}+0.026 \quad (1)
\]

The stiffness of the fracture reduction fixator is 88.5N/mm calculated by finite element method.

4.2 Experimental results of axial loading

4.2.1 The voltage value correction result of the electronic universal testing machine
Use 2kg and 4kg weights to calibrate the loading value of the WD-I electronic universal testing machine and record the voltage value. When a 2kg weight is used for loading, the voltage value displayed by the testing machine is 38; when a 4kg weight is used for loading, the voltage value displayed by the testing machine is 77. Take the average of the two loading values as the experimental data, that is, when the applied force is 1N, the voltage value is 1.917.

4.2.2 Universal testing machine loading results
After confirming the voltage correction result of the electronic universal testing machine, start to load the fracture reduction fixator, and record the changes of the loading value and the loading distance of the electronic universal testing machine when the loading time is 15s, 30s, 45s, 60. Repeat the above steps 5 times, 5 times the relationship between loading time and loading distance is consistent: loading time is 15s, loading distance is 0.5mm; loading time is 30s, loading distance is 1mm; loading time is 45s, loading distance is 1.5mm; loading time is 60s, The loading distance is 2mm; the loading value results of the electronic universal testing machine for 5 times are counted, and the statistical results are shown in Table 3. Take the average value to calculate the loading force during the period.

| Time (S) | First  | Second | Third  | Fourth | Fifth  | Average | Loading force (N) |
|----------|--------|--------|--------|--------|--------|---------|-----------------|
| 15       | 70     | 69     | 73     | 71     | 75     | 71.5    | 37.350          |
| 30       | 152    | 155    | 160    | 159    | 163    | 157.8   | 82.316          |
| 45       | 243    | 251    | 257    | 256    | 258    | 253     | 131.977         |
| 60       | 342    | 355    | 360    | 360    | 362    | 355.8   | 185.602         |

4.2.3 Relationship between axial loading force and displacement
From the above experimental results, the relationship between the axial loading force and displacement of the fracture reduction fixator can be calculated as follows: when the loading distance is 0.5mm, the loading force is 37.350N; when the loading distance is 1mm, the loading force is 82.316N; When the loading distance is 1.5mm, the loading force is 131.977N; when the loading distance is 2mm, the loading force is 185.602N; the relationship between the axial loading force and displacement of the fracture reduction fixator is plotted as a scatter diagram, as shown in Figure 4.
It can be seen from Figure 4 that the axial loading force and displacement of the fracture reduction fixator are linear. In order to further explore the relationship between axial loading force and displacement, SPSS23.0 statistical analysis software is used to fit the relationship curve between axial loading force and displacement, and the variance analysis of the curve is calculated, and the significance analysis of the regression coefficient is carried out. Statistics of the analysis results are shown in Table 4. It can be seen from Table 4 that the curve fit is 0.998, and the P value of the regression coefficient significance analysis and the curve analysis of variance are both less than 0.05.

| Curve fitting | Goodness of fit | P  | Coefficient $\beta_1$ | P  | Constant $(\beta_2)$ |
|---------------|----------------|----|----------------------|----|---------------------|
| Linear curve  | 0.998          | 0.001 | 0.01                | 0.001 | 0.146               |

At this time, it can be determined that the axial loading force and displacement of the fracture reduction fixator are linear. The displacement formula can be determined from this result as:

$$\text{Displacement} = 0.011 \times \text{axial loading force} + 0.146$$ (2)

At this time, the measured stiffness of the fracture reduction fixator was 85.4N/mm.

a. Calculation and verification of the three-dimensional model of the fracture reduction fixator

The above experimental calculation results are that the axial stiffness of the fracture reduction fixator calculated by finite element modeling is 88.5N/mm, the measured axial stiffness of the axial loading experiment is 85.4N/mm, and the ratio of the two is 1.037. Due to the existence of the experiment, the influence of the interference item cannot be excluded, so the experimental results will produce certain errors. The ratio of the axial loading experiment and the actual measurement in this experiment is 1.037, which is within the error range. It can be proved that the finite element three-dimensional modeling method established in this study and the method of calculating the axial loading force of the fracture reduction fixator are feasible.

b. Discussion on the difference between finite element modeling calculation and measured stiffness

1) In the process of finite element three-dimensional modeling, in order to simplify the calculation process, when constructing the model, set the connection mode between the parts as fixed connection, without considering the relative displacement. However, in the actual measurement process, the solid mechanics model is used. There are certain differences between the two, so the calculated results have small differences. However, in actual use, the connection of the fracture fixator must be stable and reliable, so the model established in this experiment is in line with clinical application.

2) In limited 3D modeling, the default connection between the log and the fixed pin is a fixed connection. However, in the solid mechanics model, even if it has been fixed with 502 glue, relative displacement may still occur, which will have a certain impact on the experimental results, which cannot be avoided. Therefore, there will be some differences between the finite element calculation results and the actual measurement results.

After experimental comparison and result discussion, it can be confirmed that the loading parameters of the finite element 3D modeling method established in this study are consistent with the loading parameters of the solid mechanics experiment. Therefore, it is proved that the finite element three-dimensional modeling method established in this study and the method of calculating the axial loading force of the fracture reduction fixator are feasible.

5. Conclusion

In this study, a three-dimensional model of the fracture reduction fixator and the calculation model of axial loading force were established on the basis of finite element, and the experiment was designed. The three-dimensional finite element modeling method and the calculation model of the axial loading force of the fracture reduction fixator were used as experimental items. The solid mechanical model of the fracture reduction fixator is a comparison item. The experimental results show that the loading parameters of the three-dimensional finite element modeling method established in this study are consistent with the loading parameters of the solid mechanics experiment, which confirms the
effectiveness of this research. Therefore, the finite element three-dimensional modeling and calculation method established in this research can be used for the related research of fracture reduction fixator.

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