Three Kinds of Novel Bioabsorbable Interface Screws:
Evaluation of Mechanical Properties

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Abstract. With the development of medical technology and materials science, the structure optimization method of bioabsorbable materials for implantable medical devices becomes more and more important, and the absorbable interface screw is the most representative device in implantable medical devices. Based on the previous parametric design method for the loading and structural characteristics of the interface screw, this paper assembled the interface screw and cancellous bone with the tunnel hole and simulated the graft fixation after cruciate ligaments surgery. In this study, through the finite element method, the mechanical properties of interface screws with different structural parameters obtained by parametric design were comprehensively evaluated from the aspects of stress and strain energy density.

1. Introduction
Interface screws is widely used in cruciate ligaments reconstruction surgery to fix the graft, to meet the rigid fixation of graft without slippage in the early rehabilitation process [1]. With the development of material technology, the appearance of bioabsorbable materials provides a new choice for interface screws. Its degradation products can participate in the metabolism of human body, so it is widely used in cruciate ligaments surgery to fix the graft [2]. The mechanical properties of bioabsorbable interface screws are not only affected by material properties, but also related to structural design [3,4]. In the early stage, the research on interface screw was mainly based on experimental methods. Weiler [4] measured the pull-out force, fixation stiffness and insertion torque of interface screw fixation by insertion and pull-out experiments on absorbable interface screws of six kinds of different materials and structures. It was found that the five kinds of biodegradable screws provided the same initial pull-out force and fixation stiffness as the traditional titanium screws.

With the development of computational mechanics, in addition to the method of testing biomechanical properties in vitro, the finite element numerical simulation method is widely used to analyze the mechanical properties of interface screws [5,6]. Abdullah [6] carried out finite element analysis on interface screws of different materials by applying a 200 N tensile force (the approximate value of the graft tension when fully extended in gait) to the interface screws as the loading condition. It was found that the von Mises stress of interface screws of femoral and tibial tunnels increased with
the increase of material hardness, and the maximum displacement showed the opposite trend. Alex [2]
found that the influence of the number of holes on the pull-out force and insertion torque of absorbable
interface screw was studied by finite element method.

In this study, a 2D axisymmetric finite element model including cancellous bone was established for
three kinds of interface screws with different structural parameters, and the mechanical properties of
interface screws were comprehensively evaluated from the aspects of stress and strain energy density.

2. Materials and methods
At present, the biomechanical simulation of interface screw focuses on the reduction of the operation
process, in order to accurately predict the trend and value. In order to improve the efficiency of
simulation, 3D models was simplified to 2D models. As a common simplification method, 2D
axisymmetric analysis has been widely used in solid, fluid and multi field coupling mechanical analysis
of various axisymmetric structural characteristics, and there were a few applications for screw parts.
The axial symmetry of the interface screw and cancellous bone could be simplified, but the axial
symmetry would simplify the screw lead. In addition, the finite element method could not simulate the
characteristics of the screw effect, which makes the screw surface not the dominant factor in the analysis.
Therefore, the 2D axisymmetric analysis only needed to ensure the tangential projection of the screw
thread.

The ligament in the analysis of interface screw fastening system could not appear in the simplified
plane because of its asymmetric characteristics, but the existence of ligaments did not affect the
simulation results. First of all, the ligaments' role in the simulation was to transfer torque to the interface
nail, which was an unknown quantity of the numerical model and needs to be solved by displacement
to drive the stiffness matrix. The ligament did not provide a known quantity in the solving equation,
which was not a necessary condition for the performance analysis of the interface screw. Secondly, the
ligament provided the interference needed for the contact pressure between the tunnel and the interface
screw, which can be replaced by reducing the diameter of the tunnel. Many scholars had proved that the
mechanical property data without ligaments was consistent with the experimental data [7-9]. To sum up,
the simplified 2D simulation is about the nonlinear friction contact relationship between the screw body
and the tangential projection of the bone canal.

2.1. Validation of 2D axisymmetric finite element model
The nonlinear finite element equations were solved by Newton Raphson method. Firstly, the rationality
of the simplification of the 2D axisymmetric model was verified by comparing with the 3D model.
Figure 1 is the stress distribution diagram of the screw when it was pulled out. It can be seen that the
stress distribution is basically the same, and the maximum stress difference is less than 10%. In order to
improve the efficiency of parametric design and finite element analysis, this paper thought that the
simplification of the 2D axisymmetric model was completely reasonable and efficient, so the 2D
axisymmetric model was used in the future research.

![Figure 1 Von-mises stress distribution: (a) 3D; (b) 2D.](image)
2.2. Finite element models of interface screw fixation

The screw models of the three kinds of interface screws (Figure. 2) were obtained through the previous parametric design, and their specific structural parameters are shown in Table 1.

![Figure 2: Three kinds of interface screws and their fixation models](image)

Table 1 Structural parameters of interface screw

| Screw-number | \(l_c\)(mm) | \(l_b\)(mm) | \(l_c\)(mm) | \(h_b\)(mm) | \(\theta_b\)(rad) |
|--------------|-------------|-------------|-------------|-------------|-----------------|
| M1           | 3.1         | 13.7        | 4.2         | 0.7         | 0.55            |
| M2           | 6.9         | 11.2        | 3.9         | 0.55        | 0.62            |
| M3           | 6.4         | 11.5        | 4.1         | 0.55        | 0.63            |

In order to quantitatively evaluate the mechanical properties of different types of interface screws, a finite element method based on ABAQUS was used for numerical analysis. In this study, three 2D models of interface screws and cancellous bone with three different structural parameters were established. Figure 3 shows the 3D models of three kinds of interface screws and the 2D models of their assembly with cancellous bone.

![Figure 3: Three kinds of interface screws and their 2D fixation models](image)

The interface screws in this study were made of polylactic acid by injection molding. The young's modulus of cancellous bone is 350 MPa and Poisson ratio is 0.3. The boundary conditions are shown in Figure 4, in which the surrounding of the loose bone tunnel was fixed and symmetrical boundary condition was located on the symmetry axis. The load was divided into two steps, in the first step, the edge near symmetry axis of screws was fixed. The average thickness of the ligaments after compression was known to be 1mm, so the unilateral interference distance was set up to 1 mm. In this step, the screw surface and the bone tunnel surface were set as contact relationship, and the extrusion of the two surfaces was realized by adjusting the interference fit of the model to contact. In the second load step, the axial displacement of screws was 0.3mm.
3. Result

Strain energy density is the common embodiment of material deformation, stress and strain. As an energy analysis method, it evaluates the elastic-plastic properties of screws in the loading process. The energy stored in the loading process of elements is strain energy, while the strain energy per unit volume is strain energy density. Fig. 5 and Fig. 6 show the distribution of strain energy density of interface screw and bone tunnel, respectively.

As previously studied, strain energy density distribution was considered to be a key factor affecting
bone remodeling after cruciate ligaments reconstruction. The higher strain energy density distribution around the bone tunnel might lead to the risk of tunnel expansion and damage to the bone tunnel wall [10]. According to the strain energy density analysis results of bone tunnel shown in Figure 6, M3 screw produced higher sed distribution in cancellous bone, followed by M2 and M1.

In addition to analyzing the stress distribution of screws and the internal strain energy density of cancellous bone, the performance of each screw can be compared. The Von-Mises stress distribution along the screw body during insertion is shown in Figure 7.

![Figure 7](image)

Figure 7  Von-mises stress distribution of screws

Three kinds of screws parameters show different characteristics, where the stress of M1 is concentrated in the head and tail, the stress of M3 is concentrated in the middle and the stress distribution of M2 is relatively uniform. Combined with the performance index and design parameters, it was found that the change of design parameters had obvious effect on the mechanical characteristics of interface screw.

The strain energy density around the bone tunnel of M1 was the smallest and the stress distribution in the M1 was more uniform after inserted, so it was considered to have the best mechanical properties among three kinds of interface screws.

4. Conclusion
In the process of screw development, in order to determine the material and structural parameters of the screw, a lot of tests need to be done on the screw. Although the test method is relatively reliable, it wastes a lot of time and cost, and the test process time is very short, so it is difficult to accurately observe the micro process of thread change. Combined with parametric modeling and finite element analysis, this paper analyzed three kinds of interface screws with different structural parameters, and comprehensively evaluated the mechanical properties of the three kinds of interface screws.

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