Retraction

Retraction: A Novel Parametric Design Method of Three-section Bioabsorbable Interface Screw (*J. Phys.: Conf. Ser.* 1986 012062)

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A Novel Parametric Design Method of Three-section Bioabsorbable Interface Screw

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Abstract. Bioabsorbable interface screw is a kind of fixation instrument which uses interference fit to produce tightening force. The mechanical properties of interface screws, which are mainly used for cruciate ligament reconstruction surgery, have a strong correlation with thread parameters. Due to the different contact stresses caused by the different contact environments of each section of the interface screw after knee ligament reconstruction, this paper proposed a parametric design method for the three-section interface screw. In this study, the cross-section perpendicular to the axis was used as the reference plane for modeling, and a mathematical model of the structural parameters of each cross-section was established. Finally, through the python module of the open design platform GRASSHOPPER, the mathematical model established was applied to the parametric design of the interface screw.

1. Introduction
Bioabsorbable interface screw is an implantable medical device for knee ligament reconstruction, which provides a tibial fixation point for the distal ligament [1]. Since the introduction of interface screw in 1997, its structure and material have been optimized and iterated rapidly. So far, it has developed into the third generation of absorbable interface screw. Structural optimization design is always the core issue of interface screw, and the relationship between design parameters and performance is the main content of research. Tanya and colleagues carried out polyurethane block pull-out force experiment on screws with different pitch and taper [2], and verified the influence of the change of pitch and taper on the fastening performance. Although the contact area between screw and bone canal does not affect its static friction resistance, too small area will cause excessive local pressure and damage ligament. In order to reduce the screw in torque and obtain a good pull-out force, Athwal changed the pitch and lead of the screw head, and found that the screw with variable pitch treatment reduced the screw torque on the premise of ensuring the same pull-out force, which provided an experimental and theoretical basis for the variable pitch design of the screw [3], compared with the screw before variable pitch treatment.

Finite element simulation is an important step in the performance verification stage of interface screw, which is used to discuss the relationship between design parameters and mechanical response [4]. Jenny and Chang researched mechanical properties of the screw based on finite element analysis, and then
redesigned the parameters such as pitch, thread depth, thread length and diameter according to the analysis results, and obtained the expected results [5]. Quispe proposed and studied a design method of segment connection to construct continuous sandwich pipeline. A two-dimensional numerical analysis of the threaded connection was carried out using nonlinear finite element method, and the contact stress and maximum tension under the action of torque, external pressure and axial load were obtained by applying compensation torque instead of radial interference, and the results proved that threaded connections are a feasible solution, especially for watertight requirements under compound load [6].

When analyzing the mechanical properties and designing the structure of the thread, it is necessary to establish the geometric model and finite element model of the thread repeatedly. If every design needs to model the thread from the beginning, the work efficiency will be greatly reduced, and the research and development progress will be slow. In this paper, parametric design and finite element analysis are combined, and a set of design and analysis method for interface screw is proposed. The parametric design transforms the interface screw into the parametric equation of spatial analytic geometry, and controls the structural features of the interface screw dynamically with the constraints of size variables and graphic relationship. The parametric CAD models with different features can be obtained by inputting a variety of combinations of variables.

2. Design Method
As a medical implant screw, it is mainly used for knee ligament reconstruction. Its contact pressure depends on the compression between the bone tunnel and the autogenous or artificial soft tissue. In order to design interface screws with good mechanical properties, including both a smaller screw-in torque and a larger axial pull-out force, this paper proposed a design method of interface screws with variable thread, variable pitch, and variable diameter at the same time. According to different design requirements, the pitch, diameter and thread lead of these three parts are also different. The interface screw is divided into three parts: head (A), middle (B) and tail (C). Figure 1 is design drawing of three-section interface screw.

2.1. Parameterized mathematical model
On the basis of computer graphics, the forming of parametric design mechanism is to describe the geometric characteristics through the graphic algorithm in mathematics. The graphic algorithm is based on points, and gradually deduces the surface, body, domain, vector in space and even the physical quantities in computational mechanics by using parameters. The computer can quickly complete a large number of matrix operations in graphic relations. In this paper, the cross-section of the vertical and axis
is selected as the modeling datum plane, and the interface screw is deconstructed into multiple cross-
sections in the space, which can more accurately control the shape of the spiral surface and adjust the
design parameters according to the performance index of the screw, so as to achieve the purpose of
optimization design. Figure 2 is the cross section perpendicular to the axis of the screw.

![Figure 2: The cross section design of interface screw](image)

The cross section includes the root circle and thread shape profile of the interface screw, as shown in
the red and blue arcs in Figure 1, respectively. The radii of root circle are as follows:

\[ R_i = 0.5D_i \quad i = a, b, c \]  

(1)

The radius of thread shape \( r_i \):

\[ r_i = \frac{2h_i + D_i}{4} \quad i = a, b, c \]  

(2)

The intersection of the two profiles is G and E, and the corresponding angle is \( \theta_1 \) and \( \theta_2 \), and its
expressions are:

\[ \theta_1 = \arcsin\left(\frac{2D_i}{2h_i + D_i}\right) \]  

(3)

\[ \theta_2 = \pi - \arcsin\left(\frac{2D_i}{2h_i + D_i}\right) \]  

(4)

The polar coordinate system, \((\rho', \theta')\), is established. For the polar diameter of any point on the outer
profile of cross section A, B and C, the expression of corresponding three sections is as fellow:

\[ \rho' = \begin{cases} \frac{D_i}{2} & 0 \leq \theta \leq \theta_1 \\ \left(h_i + \frac{D_i}{2}\right) \sin \theta & \theta_1 \leq \theta \leq \theta_2 \end{cases} \]  

(5)

\[ (i = a, b, c) \]

In order to rotate the plane projection into a spiral plane, the polar coordinate expression is needed
to cylindrical coordinates \((\rho, \phi \text{ and } z)\). For each cross-sectional projection \( \rho \), there is always a mapping
\( \rho' \) corresponding to it. \( \rho' \) is a rotating projection of \( \rho \). For a constant lead, diameter and tooth height, the
relationship between the rotation and distance is:
\[
\rho = \rho'\left(\frac{2\pi}{s} \cdot z\right) \tag{6}
\]

For Section B, its lead \(s_b\) and diameter \(D_b\) are not changed, so the mathematical model of section B in cylindrical coordinates is obtained by substituting formula (5) into formula (6):

\[
\rho_b = \begin{cases} 
\frac{D_b}{2}\left(\frac{\varphi - 2\pi z}{s_b}\right) & 0 \leq \varphi \leq \theta_1 \cup \theta_2 \leq \varphi \leq 2\pi \\
\left(h_b + \frac{D_b}{2}\right)\sin\varphi\left(\frac{2\pi z}{s_b}\right) & \theta_1 \leq \varphi \leq \theta_2
\end{cases}
\tag{7}
\]

For section A and C, the thread height, lead \(s\) and diameter \(d\) all change with the height \(z\), so equation (6) is no longer applicable:

\[
\rho = \frac{r(z)}{r(0)} \cdot \rho'\left(\frac{2\pi}{s(z)} \int^z dz\right) \tag{8}
\]

The cross section includes the root circle and thread profile of the interface screw, as shown in the red and blue arcs in Figure 2. The radii of root circle were as follows:

\[
r_a(z) = 1.5 + z\left(\frac{D_b - 3}{2l_a}\right) \quad 0 \leq z \leq l_a \tag{9}
\]

\[
r_c(z) = \frac{D_b}{2} + (z - l_a - l_b)\frac{7.5 - D_b}{2l_a} \quad l_a + l_b \leq z \leq L \tag{10}
\]

\[
r_a(0) = 1.5 \text{ mm} \quad r_c(0) = \frac{D_b}{2} \tag{11}
\]

By substituting (5) and (9) - (11) into (8), the mathematical models of A and C are obtained as follows:

\[
\rho_a = \begin{cases} 
\left(\frac{r_a(z)}{r_a(0)}\right)^2\left(\varphi - 2\pi\int^{l_a}_{0} dz\right) & 0 \leq \varphi \leq \theta_1 \cup \theta_2 \leq \varphi \leq 2\pi \\
\left(\frac{r_a(z)}{r_a(0)}\right)\left(h_a + r_a(z)\right)\sin\varphi\left(\frac{2\pi z}{s_a(z)}\right) & \theta_1 \leq \varphi \leq \theta_2
\end{cases}
\tag{12}
\]

\[
\rho_c = \begin{cases} 
\left(\frac{r_c(z)}{r_c(0)}\right)^2\left(\varphi - 2\pi\int^{L}_{l_a + l_b} dz\right) & 0 \leq \varphi \leq \theta_1 \cup \theta_2 \leq \varphi \leq 2\pi \\
\left(\frac{r_c(z)}{r_c(0)}\right)\left(h_c + r_c(z)\right)\sin\varphi\left(\frac{2\pi z}{s_c(z)}\right) & \theta_1 \leq \varphi \leq \theta_2
\end{cases}
\tag{13}
\]

The mathematical model of B segment is (7). The pitch, lead and thread height do not change with Z. A. The mathematical model of C-segment is (12) and (13). The lead \(s\), radius \(R\) and thread height \(h\) change with \(z\). According to the parametric formula, we can get a complete spiral array of three-section design interface screw.
3. Result
The three-section interface screw parametric design is carried out by using Python module of the commonly used open design platform, grasshopper. First, the parameters of parametric design are determined as follows: $h_b$ (thread height of section C), $\theta_b$ (lead angle of section B), $l_b$ (length of section A) and $l_a$ (length of section A), the range of values and the step length of parameter change are shown in Table 1. The mathematical models (7), (12) and (13) of the three sections of the screw are then converted to codes.

| parameter | range | step size |
|-----------|-------|-----------|
| $l_a$     | $L/6 \sim L/3$ | 0.1mm |
| $l_b$     | $L/2 \sim L/3$ | 0.1mm |
| $\theta_b$| $\pi/6 \sim \pi/3$ | 0.01rad |
| $h_b$     | 0.5mm~1mm | 0.05mm |

Taking five groups of design variables as examples, this paper shows the complete process of parametric design, as shown in Figure 3 and Table 2.

4. Conclusion
The interface screw is used to fix the ligament in the bone canal by interference, and the environment requires that it is unallowed to cause secondary injury to the surrounding tissues during the fixation process, so the smoothness of the thread surface directly determines the surgical effect. For the interface screw, different from the traditional method of selecting the axial section as the thread modeling datum, this paper selected the cross section perpendicular to the axis as the modeling datum, and put forward a mathematical model suitable for the interface screw.
On the other hand, the surface quality is inevitably deteriorated by the change of multi thread feature of interface screw. The new mathematical model projection method decomposed the screw body into several axial projections. The projection graph described the variable size parameters of the screw body and the screw thread in the form of polar coordinate parameter equation. The z coordinate value was used as the coefficient to rotate and increase and decrease the variables. The projection method output a smooth multi-stage interface screw CAD model, which solved the quality problem of the model surface.

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