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Design of Orthopedic Plates and Its Modification Based on Feature

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Abstract: To quickly construct the orthopedic plates and to conveniently edit it, a novel method for designing the plates is put forward based on feature idea and parameterization. Firstly, attached to the existing or repaired bone model, the region of interest (ROI) is selected as the abutted surface of orthopedic plate, and the ROI is reconstructed to form a CAD surface. Secondly, the CAD surface is to be defined as a surface feature (SF) and then some semantic parameters are configured for it. Lastly, the plate body is constructed through thickening, and some higher parameters are defined for it so as to produce a volumetric feature (VF). In the above process, there exist two main problems: one is parameterization of the abutted surface, and the other is construction of the outer surface. Besides, the mapping relationship has to be built between surface feature parameters and volumetric feature parameters. This method supports the modification of high-level parameters, consequently promoting the quality and efficiency of orthopedic plate design.

Keywords: Orthopedic plate; Surface feature; Abutted surface; Implant design

1 Introduction

As a close conjunction of computer digital technology and orthopedics clinical, digital orthopedics has become a hot research issue since last decade [Zhong (2011)], and digital design of orthopedic implants is a key technology in digital orthopedics. It is not only of great application significance in the production of orthopedic medical devices, but also of great theoretical significance in computer aided orthopedic operations [Jin, Lian, Wang, Wang, Zhao, Liu, and Li (2013); Hao, Yu, Hao, and Feng (2012)]. Currently, in orthopedic operation, patients of bone defects and traumatic fracture need such fixed implant as internal fixation plate(orthopedic plate), bone nail, bone needle and so on, as shown in Fig. 1(a). Among them, the design of

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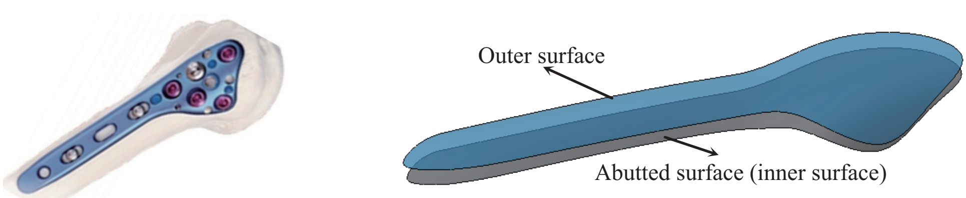
internal fixation plate is the core of implant design. The current method of designing orthopedic plate is to directly design them with commercial CAD software and plenty of man-machine interaction, having 3D mesh model of bone as a reference. This method is time-consuming and the result is unsatisfactory and inaccurate, especially in design of both abutted surface (inner surface) and outer surface, the abutted and outer surface are shown in Fig. 1(b). Generally, the plate design includes serialized and individualized design. On the one hand, patients need a great quantity of serialized orthopedic plates of various types and sizes [Joshua, Sherif, Brett, Gregory, and Carol (2013)]. In operation, doctors first choose the most suitable plate which is the closest in shape and size with the patient's bone. Then such operations as bending and trimming are needed to enable the chosen plate to match well with the patient's bone. However, the task requires tedious manual operations, even so the abutted surface sometimes fails to meet the requirements. On the other hand, due to the differences in individual bone structure and position of fracture, individualized design of orthopedic plates is needed for the purpose of obtaining an ideal abutted surface [Ren, Zhang, and Guo (2011)]. However, this individualized design is not easy to generate a general template for common use, and each design has to be from scratch.

Considering that the same type of plates has similar structure and is most suitable for parameterization as a feature, we put forward a method for quickly designing plates based on feature idea for general use. It is important to construct both abutted surface and outer surface of orthopedic plates in either serialized or individualized design. The abutted surface is similar to but different from the outer surface. The abutted surface should be constructed to match well with the fracture bone surface, while the outer surface is used to design the different thickness to ensure the different rigidity of the plate.



(a) Fixed implant (b) Abutted surface and outer surface

Figure 1: Abutted surface and not abutted surface in orthopedic plate

Recently, computer-aided orthopedic surgery is the most rapidly developing field in surgery [Joshua (2011)]. The study and application of computer-aided orthopedic implants design have been receiving more and more attention around the world.

Presently, the method of digital orthopedic implants design includes the following basic steps: First, construct the mesh model by inputting CT/MRI data, piece together and correct the broken bones; Second, reconstruct and polish the surface of the mesh model geometrically; Third, obtain the abutted surface referring to 3D mesh model of bone; Fourth, construct other surfaces to form a solid model of the implant and generate serialized products in different sizes based on medical experience; Finally, appropriately adjust the shape and thickness of the implant based on the result of finite element analysis. In recent years, the creation method of implants proposed by Lian, Liu, He, Wang, Jin, Li, and Lu (2013) laid the foundation for digital orthopedics, and it focuses on the machining method of the plates. Smith, Ellis, and Pichora (2013) made analysis and summary on computer-aided orthopedic surgery and pointed out that the design of implants suitable for most patients would be the future design tide. Liu, Huang, and Zhu (2011) proposed a simulation method to obtain the geometric parameters of the target implants before the real operation, which can create a precise model of pre-bending implants. Ren, Zhang, and Guo (2011) proposed a computer-aided method of creating a 3D solid model of anatomical implant. Song (2009) proposed an approach of repairing and reconstructing the broken bones based on the reverse technology of CT scans, and then selected a suitable implant. Joshua and Carol (2010) proposed a method of designing the abutted surface of the plate based on bone mesh model and set the suitable thickness by finite element analysis. Shen, Zhang, and Du (2011) proposed an individualized design after reversely obtaining anatomical implants plate based on the reverse engineering technology and CT scan. Neto, Marques, Marta, Leal, Couto, and Machado (2015) put forward a method from design angle, which first generates an approximate shape of the plate abutted surface based on the surface of bone model, and then trim the surface to match the needed shape for the patient. The above researches promote the development of digital orthopedics to a certain extent. However, because the orthopedic plate contains complex freeform surface, the designing and editing of it is comparatively complicated. Still, by far, the study of the plates design based on feature idea and parameterization has rarely been reported.

With respect to the parameterization of surface feature, Vergeest, Horvath, and S-panjaard (2001) propose a formal approach for depicting freeform feature, giving examples of ridge and hole features. Song, Vergeest, and Saakes (2003) suggest a parameter-driven deformation approach for defining a surface in terms of intrinsic parameters. Nyirenda and Bronsvoort (2008, 2009) propose numeric and curve parameters to define freeform features. Numeric parameters specify the usual properties, e.g., length, width, and height, whereas curve parameters can be added to feature models and modify the local shapes in styling design. Pernot, Giannini, Falcidieno, and Leon (2009); Pernot, Falcidieno, Giannini, and Leon (2008) offer an approach for parameterizing freeform feature templates to represent a surface; this approach requires a highly iterative process between the surface deformation and the feature template. Park and Lee (2005) suggest a parametric method for freeform mesh models that uses control freeform mesh. This method involves constructing a control mesh that surrounds an object model and then imposing constraints on this mesh. Langerak and Vergeest (2007) suggest one possible approach for user-driven feature definition. Freeform feature is a parametric description of a shape. Complex mappings must be constructed between control points and parameters because parametric influence is defined through the NURBS control points. The methods mentioned above are useful and meaningful for representing and parameterizing surface feature. However, because surface feature parameters is not only defined on some specified feature points but also surface pass through these points, when the values of feature parameters are changed, it is hard to continuously ensure surface to pass through the newly-created feature points and to enable the to-be-generated surface to be coincident with the original surface.

Considering that feature technology supports the setting of high-level semantic parameters and facilitates the editing of surface, our paper focuses on surface feature and parameterization for the purpose of plate design. We put forward the definition of surface feature and volumetric feature for designing orthopedic plates. Here, Surface feature is mainly used in parameterizing the abutted surface, while volumetric feature is a vital concept in describing how to generate the volumetric feature from surface feature, the core of which is to construct the outer surface. Since the outer surface of the plate is similar to the abutted surface, we can quickly construct the outer surface based on characteristic curves which are derived from newly-created points through thickness parameters.

The remainder of this paper is organized as follows: Our method is outlined in Section 2. Details of our approach are described in Section 3. Case analyses are made in Section 4. Section 5 concludes our paper and predicts our future work.

2 Overview of method

The design of orthopedic plates aims at parameterizing the abutted surface and constructing the outer surface. For one thing, the abutted surface is parameterized based on characteristic curves, while the plate body is parameterized chiefly through the generation of the outer surface. To state succinctly, the idea of the approach is as follows (see Fig. 2): Firstly, to extract the region of interest on the existing bone model by selecting the boundary; Secondly, to reconstruct the surface of the extracted region; Thirdly, to parameterize the reconstructed region to generate the surface feature; Lastly, to construct a volumetric model by generating the outer surface and then input it into the template library. The key of the process lies in parameterization of surface feature and of volumetric feature, as well as in building the mapping relationship between their parameters. Details of the steps are as follow:

Step1: Extract the region of interest from the bone model. According to medical experiences, the region of interest is extracted to match with the existing or repaired bone model, and it will become the abutted surface of orthopedic plate;

Step2: Reconstruct the extracted region to generate a CAD surface (i.e. abutted surface). The selected region is created to become a new surface based on characteristic curves;

Step3: Parameterize the constructed region to generate a surface feature, which supports setting semantic parameters on the surface. The semantic parameters can be used to edit and modify the surface shape;

Step4: Generate the volumetric feature. According to the abutted surface, the outer surface can be constructed based on characteristic curves; and then the varied thickness parameters are set at some key locations of both the abutted surface and its corresponding outer surface, then the volumetric feature is created. These thickness parameters can be edited and modified;

Step5: Export to the template library of the implant features. The generated implant features are exported to the template library after they are verified to satisfy with the functional and structural requirements through the CAE analysis.

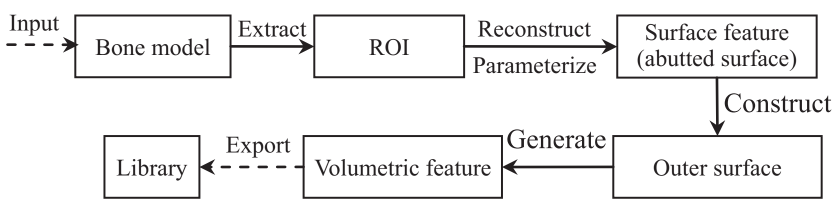


Figure 2: The flow of the approach

Among the above steps, Step 2–4 are the most important of the plate design, which are to be dwelt on in the following chapters. Fig. 3 illustrates the main process of the plate design, and the paper will detailedly describe the construction process in following sections.

3 Definition of orthopedic plate feature

The definition of orthopedic plate feature includes the definition of surface feature and the definition of volumetric feature. The key of the definition of surface feature

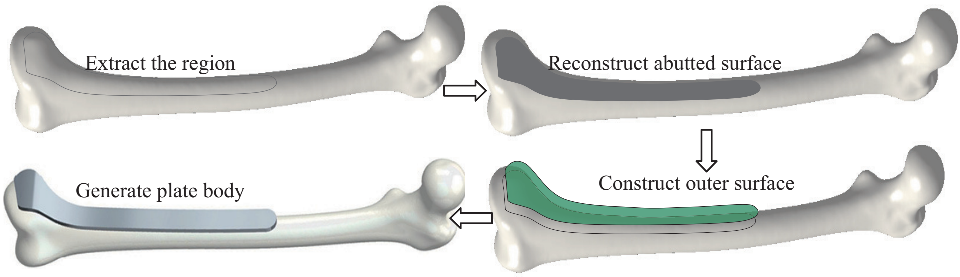


Figure 3: Main steps of orthopedic plate generation

lies in how to parameterize the shape feature containing freeform surface [Langerak (2010)]. The key of the definition of volumetric feature lies in how to construct the plate body from the surface feature.

3.1 Definition of surface feature

The surface is constructed with surface generation method based on characteristic curves [He, Chen, Jiang, and Wand (2014); Qin and Wright (2006)]. The parameters of surface feature are defined on some key points of characteristic curves (these key points are called feature points). The definition of surface involves selecting the local region from bone surface model and extracting the geometric elements, while the core of surface feature definition is parameterization. Firstly, select and reconstruct the ROI to generate an independent CAD surface; Secondly, parameterize the reconstructed surface to generate a surface feature, so that each parameter has a certain semantics. The reconstructed surface feature should be reusable, editable, transplantable for the purpose of being redesigned. The detail steps are as follows.

Step1: The boundary curve of ROI is selected and defined on bone model. The ROI is reconstructed as the abutted surface, as shown in Fig. 4(a, b);

Step2: The interior constraint curves are defined on the region. These curves are the skeleton curves which are the sharper curvature within the region, as shown in Fig. 4(c), and they support human-computer interaction [Leif and Richard (2011)];

Step3: A new and independent CAD surface is reconstructed based on the above characteristic curves with surface generation method, such as the filled method and the skinned method, as shown in Fig. 4(d);

Step4: The feature parameters are defined on feature points of characteristic curves, as shown in Fig. 4(e).

As for the surface parameterization, the parameters of surface feature are divided into three levels [He, Chen, and Zhao (2011)]. High-level semantic parameters describe the global shape of surface feature; Middle-level parameters describe the shape of feature curve; Low-level parameters describe the points on the surface and characteristic curves. In this paper, the surface feature parameters refer to the high-level semantic parameters.

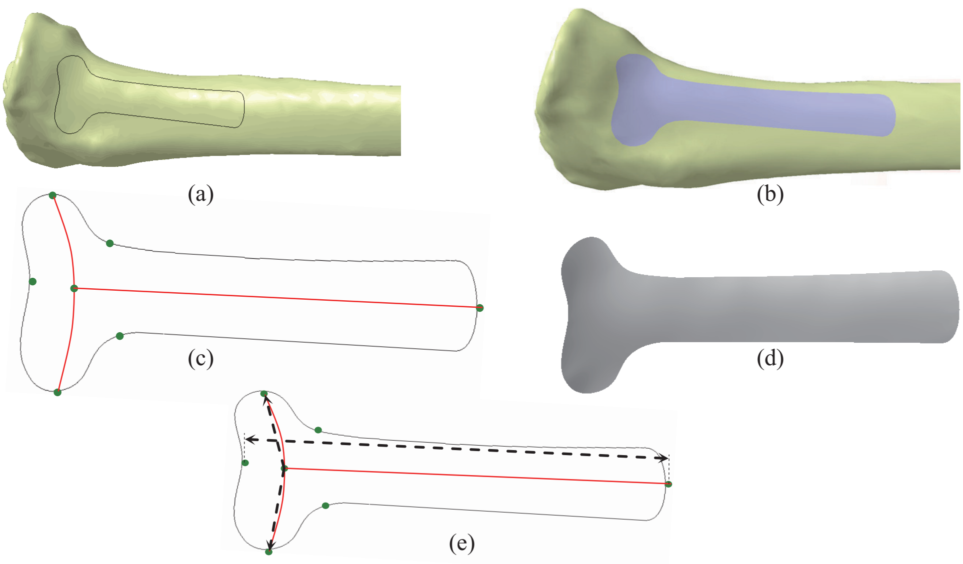


Figure 4: Region, boundary, interior curves and feature points

3.2 Definition of volumetric feature

On the basis of the generated surface feature, the volumetric feature is firstly created by setting the thickness parameters on the key points of characteristic curves of the abutted surface and outer surface. The feature parameters of orthopedic plate mainly include two types: one type is the parameters of surface feature, which describe the abutted surface of the plate; the other type is the parameters of volumetric feature, which describe the varied thickness of the plate. Besides, it is important for building the mapping μ between the surface feature parameters and the volumetric feature parameters.

As the foundation, surface feature parameters are first defined on the key points of characteristic curves of its own, and then the volumetric feature parameters are defined on the key points of characteristic curves of the two surfaces. The process of defining volumetric feature is shown in Fig. 5. The formal definition of the mapping relationship between the two types of parameters is as follows.

$\mu(P_i, Q_i, S_0) = S_1,$

where P_i is the parameters of surface feature, Q_i is the parameters of volumetric feature, S_0 is the original shape of orthopedic plate, S_1 is a new shape, and μ is the mapping between the two types of parameters. It shows how the orthopedic plate S will change with the parameters P_i and Q_i under the regulation of μ.

Firstly, the surface feature parameters P_i dominate the abutted surface shape. When the parameters P_i are changed, the shape and size of the plate will change with it.

Secondly, the volumetric feature parameters Q_i imply the plate thickness. When the parameters Q_i are changed, the shape of outer surface will change accordingly.

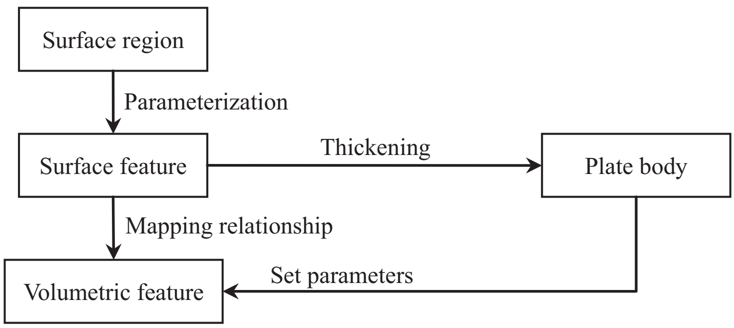


Figure 5: The process of defining volumetric feature

After the parametric definition of orthopedic plate, the plate shape can be diversified by changing the values of parameters, so as to obtain an ideal plate for the patient. Fig. 6 shows how the plate varies with different values of thickness parameters.

4 Method for designing orthopedic plate

As there are various types of fractures, the existing types of plates cannot fully and perfectly meet with the requirements of complex cases of fractures. An approach for rapidly designing the orthopedic plate is proposed to promote the anastomosis between the plate and the broken bone. Our research focuses on how to design the orthopedic plates and on how to build the mapping relationship between hierarchical parameters of surface feature and volumetric feature.

4.1 Design of orthopedic plate

In order to promote the efficiency and quality of designing orthopedic plates, the plate design mainly involves two parts: construction of surface feature, and gen-

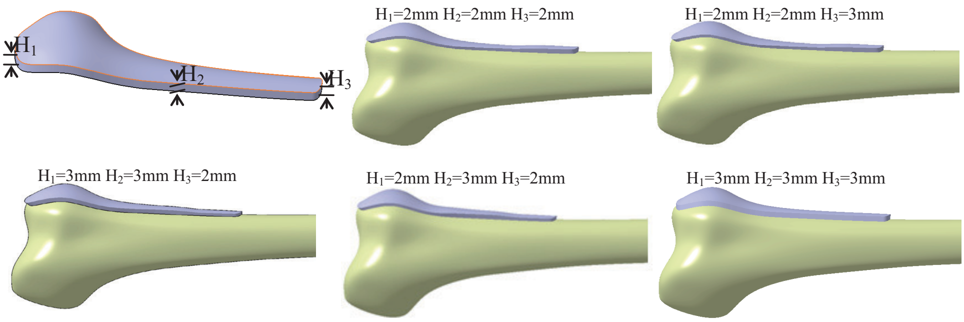


Figure 6: Changes of the plate with different thickness parameters

eration of volumetric feature. Here, construction of surface originates from characteristic curve; whereas, with B-spline interpolation method, curve is generated through the key points used to define semantic parameters.

4.1.1 Construction of surface feature based on characteristic curves

In the process of surface feature-based modeling, vertices, curves and faces constitute the geometrical elements of surface feature. The characteristic curve not only is the basic unit of modeling but also contains the characteristic information, so it determines the silhouette of surface feature [Chen (2009)]. In order to rapidly construct the anastomosis between the orthopedic plate and the broken bone, we, by attaching to the surface of bone model, select the ROI with boundary curve as the abutted surface. It is convenient for us to quickly extract and edit the region.

During the construction of the surface, according to the global shape of the original bone surface, a new surface can be generated by choosing a proper surface generation method [Gupta and Gurumoorthy (2012); Pan and Skala (2011)], such as skinned, filled and lofted. The detailed steps are shown in Fig. 7.

The orthopedic plate is mainly made up of the abutted surface (inner surface) and the outer surface. The abutted surface is similar to the outside surface, and they are only different in the detailed shape. To meet the requirement of the orthopedic plate shape, the approach for constructing surface based on characteristic curves is put forward. The abutted surface can be constructed with the boundary and interior curves by filled surface method. The abutted surface and outer surface are built as follows:

Step 1: To obtain or draw a closed boundary curve on the existing bone model, the boundary curve is shown in Fig. 7(a);

Step 2: To select the interior constraint curves or draw the user-defined constraint curves within the closed region on important locations, as shown in Fig. 7(b);

Step 3: To define the key points on characteristic curves. These key points, which are a part of curve interpolation points, are basic elements in defining surface parameters and volumetric parameters, as shown in Fig. 7(c). The shape of surface can be quickly edited by these semantic parameters when surface feature was constructed; besides, the detailed shape can be modified with these key points;

Step 4: To generate the abutted surface of bone model via the execution of filled or skinned method, as shown in Fig. 7(d, e). Fig. 7(d) shows the filled surface based on boundary and interior constraint curves with filled surface method, and Fig. 7(e) shows the final abutted surface.

Step 5: To construct the outer surface. The outer surface includes characteristic curves and key points originated from those on the abutted surface. Based on these newly-created curves, the outer surface is constructed in similar way with Step 4, as shown in Fig. 7(f).

During the above process, the boundary curves and the interior constraint curves serve as characteristic curves, respectively determining the scope and basic shape of the generated surface. Besides, some key points are defined on these characteristic curves and are used as basic elements in defining parameters of surface feature and volumetric feature.

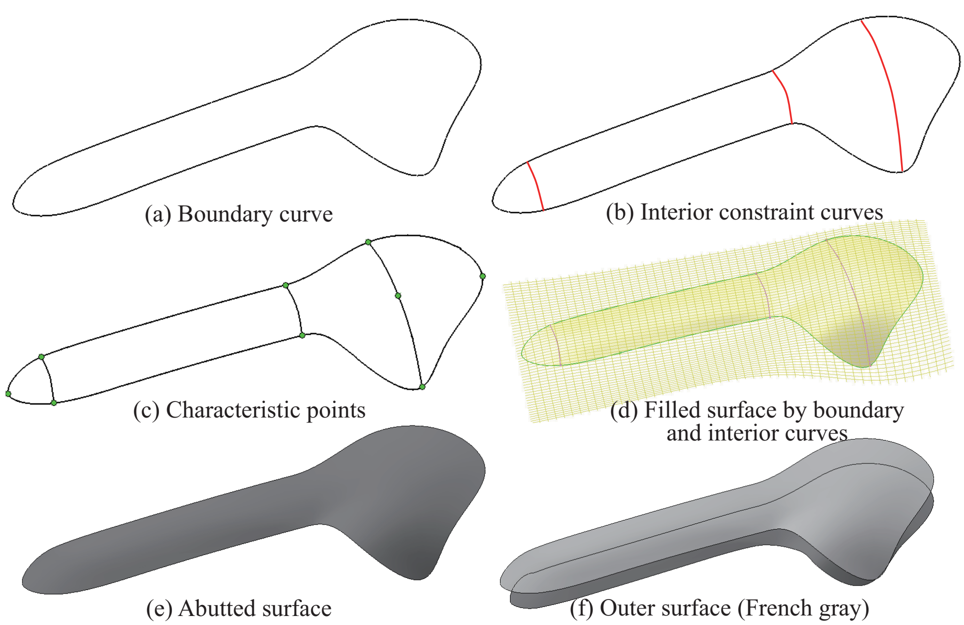


Figure 7: The generation of abutted surface of plate

4.1.2 Generation of volumetric feature

Based on surface feature construction in section 4.1.1, an implant volumetric feature with varied thickness parameters is to be built to form its basic shape. Then surface feature and volumetric feature are semantically parameterized according to the medical requirements. This process mainly includes the modeling of volumetric feature and its parameterization.

In the modeling of volumetric feature, the abutted surface and outer surface are the two major components. The generation of the outer surface is the comparatively more important in aspect of rigidity. Firstly, the key points, i.e. feature points, which belong to interpolation points and are used to define semantic parameters, are chosen on the abutted surface $E = \{e_0, e_1, e_2, e_3, e_4, e_5, e_6, e_7, e_8\}$, as shown in Fig. 8(a), and then the points extend towards vector direction and the extending lengths are the values of thickness parameters, thus generating the new points $E' = \{e'_0, e'_1, e'_2, e'_3, e'_4, e'_5, e'_6, e'_7, e'_8\}$, as shown in Fig. 8(b); Secondly, the new boundary curve and the constraint curves are generated with these points E' via the interpolation algorithm, which will be described in Section 4.1.3, and then the surface is constructed with filled surface generation method, as shown in Fig. 8(c); Finally, the plate body is produced through stitching the two surfaces, as shown in Fig. 8(d). The detailed steps are as follows.

Step1: Set the varied thickness parameters on the key points between the abutted surface and outer surface. Generally, the point set E is firstly specified on characteristic curves of the abutted surface according to the design requirement. And then after the thickness parameters are confirmed, the key point set E' can be automatically produced on the outer surface, as shown in Fig. 8(a, b);

Step2: Sometimes it is necessary to add some points on characteristic curves of the outer surface. These points are generated with the interpolation algorithm. Suppose any necessary point be e'_x, (the corresponding point on the abutted surface is e_x). If e'_x is between e'_i and e'_{i+1} (their corresponding points on the abutted surface are e_i and e_{i+1}), the point e'_x is determined by the interpolation formula:

$$e'_x = e_x + \lambda\overrightarrow{(e_i, e'_i)} + (1-\lambda)\overrightarrow{(e_{i+1}, e'_{i+1})}, \;\; \lambda = \frac{\|(e_x, e_{i+1})\|}{\|(e_i, e_{i+1})\|}, \;\; \lambda \in [0,1]$$

where $\overrightarrow{(e_i, e'_i)}$ is the vector from the point e_i to e'_i; $\|(e_i, e_{i+1})\|$ is the distance from e_i to e_{i+1}.

Step3: The characteristic curve on the outer surface is generated. Based on the key points and the generated supplementary points by Step 2, the characteristic curve on the outer surface is constructed with these points by interpolation curve.

Step4: The outer surface is constructed. With the characteristic curves on the outer surface created in Step3, the outer surface is constructed with filled surface generation method.

Step5: The plate body is generated through stitching the abutted surface and outer surface.

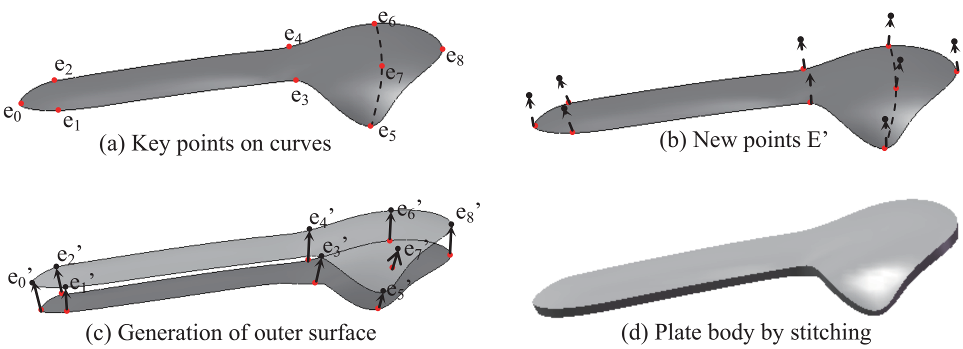


Figure 8: Generation from surface feature to volumetric feature

4.1.3 Generation of characteristic curves on outer surface

Poldermann and Horváth (1996) asserts that, for surface feature, each feature parameter must be understandable and semantic, and the total amount of feature parameters is limited. In this paper, surface feature is constructed based on characteristic curves and feature parameters are defined on the key points of characteristic curves, while characteristic curve is generated through interpolation points. Here, we construct the characteristic curve of outer surface with B-spline interpolation method [Fang and Hung (2013)], so it is of great importance on how to obtain the interpolation points. The key points are used to define semantic parameters; besides, these points are basic element of curve and are also interpolation points.

Once the abutted surface is created based on characteristic curves and the thickness parameters are confirmed, the characteristic curves of outer surface can be quickly generated, and then its surface is to be also constructed. The main steps are as follows.

Step1: Feature points on the abutted surface are defined on characteristic curves by users. Firstly, the characteristic curves, which are generated through interpolation points with B-spline interpolation method, are defined to create the abutted surface, as shown in Fig. 9(a). And then some key points from interpolation points are selected as feature points which are used to define parameters, as shown in Fig. 9(b).

Step2: Feature points on the outer surface are automatically generated with the thickness parameters and other points can be also generated with interpolation formula. Fig. 9(c, d) respectively show feature points and interpolation points on one characteristic curve of outer surface.

Step3: Characteristic curve of outer surface is generated with B-spline interpolation method, as shown in Fig. 9(e). When the required curves can be completely generated, the outer surface is to be constructed based on characteristic curves.

Step4: New curves are generated when parameter values are changed. Because the semantic parameters are defined on feature points of characteristic curves, when the parameter values are changed, the locations of feature points will be changed and new locations are to be generated. And then other interpolation points will be caused to change, these new points are to be generated with interpolation formula, as shown in Fig. 9(f).

Through the above steps, a new outer surface can be constructed based on new characteristic curves. Fig. 9(g) shows one new generated outer surface when one characteristic curve is changed with varied thick parameter value.

4.2 Mapping relationship between parameters of surface feature and volumetric feature

The key of designing the implant feature lies in the correlation relationship between surface feature and volumetric feature. There are two main problems: One is how to generate the volumetric feature from the abutted surface feature (described in Section 4.1). The other is how to establish the mapping relationship between parameters of surface feature and parameters of volumetric feature, as shown in Fig. 10. In this way, the shape of volumetric feature changes with the variation of surface feature parameters, and vice versa.

Mapping relationship between parameters of surface feature and volumetric feature

To conveniently edit and modify the implants, semantic parameters have been defined on the plate, which can be divided into two types of parameters: surface parameters and volumetric parameters. Surface parameters are used to describe the shape of the abutted surface; volumetric parameters are regarded as higher parameters used to describe the different thickness in different locations. In general, the two levels parameters are correlative. To conveniently edit the plate from different levels, the mapping mechanism needs to be established.

The core is to build the constraint relationship between parameters and to establish the bidirectional mapping relationship μ between volumetric feature parameters Q and surface feature parameters P. The building theory of mapping relationship between parameters can be seen in our previous work [He, Chen, Jiang, and Wand

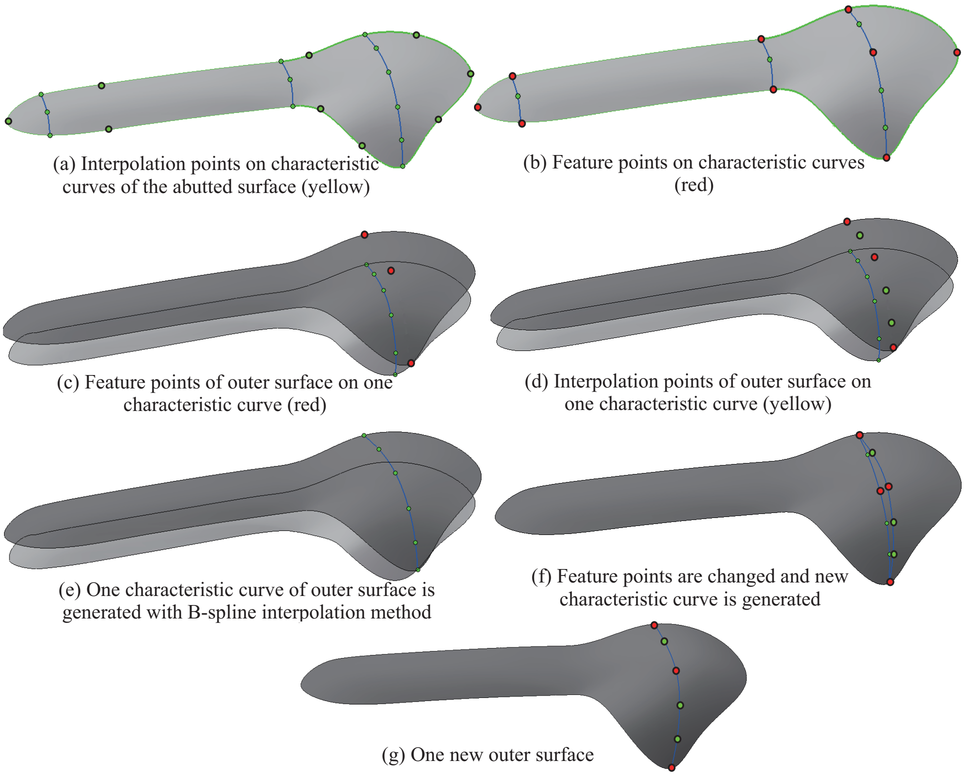


Figure 9: Generation of characteristic curve on outer surface

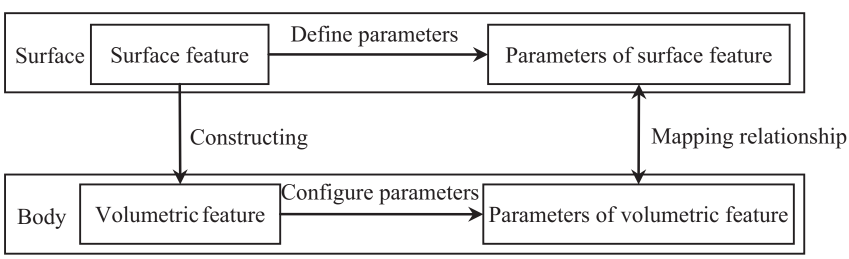


Figure 10: The mapping relationship between surface and volumetric

(2014)]. The parameters are defined based on feature points, as shown in Fig. 10(a). The mapping relationship is established on the basis of parameters and its formal formula is $\mu(P,Q,S_0) = S_1$.

For example, the instantiation is shown in Fig. 11.

The surface feature parameters: $P = \{L,W,W_1,W_2,\alpha\}$, the parameters L,W express the length and width of the plate, as shown in Fig. 11(a);

The volumetric feature parameters: $Q = \{H_1, H_2, H_3, H_4, H_5\}$, the H_i in Q means different thickness of the plate, as shown in Fig. 11(b).

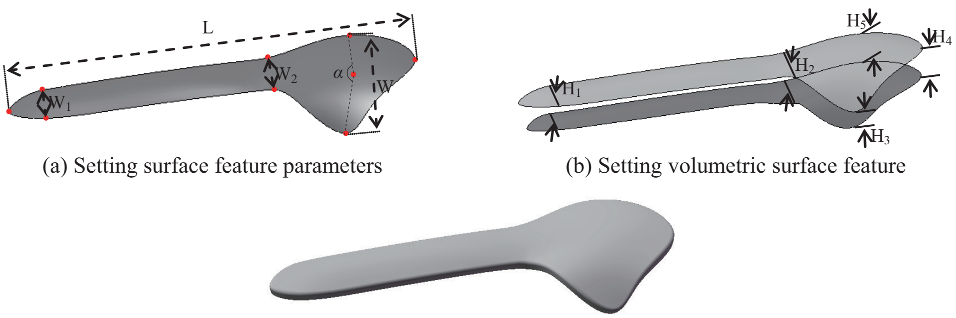
The constraint relationship between parameters: $L = 4 * W, W_1 = W_2, W = 3 * W_2$, $H_1 = H_2, H_5 \leq H_2, H_3 \leq H_5, H_4 \leq H_5, \alpha \in (3\pi/4, \pi), W_1 > 5 * H_1$ & $W_1 < 10 * H_1$;

The mapping relationship between parameters: $\mu = \{\mu_L, \mu_W\}$,

$\mu_L = \{L -> W_i, L -> H_i\}$, it means that the width W_i and thickness H_i will be subsequently changed if L is changed;

$\mu_W = \{W -> W_i, W -> H_i\}$, it means that the width W_i and thickness H_i will be subsequently changed if W is changed;

The instantiation is shown in Fig. 11(c): $L = 24$cm, $W = 6$cm, $W_1 = W_2 = 2$cm, $\alpha = 4/5\pi$, $H_1 = H_2 = 3$mm, $H_3 = 2.5$mm, $H_4 = 2$mm, $H_5 = 3.5$mm.



(a) Setting surface feature parameters

(b) Setting volumetric surface feature

(c) Plate body

Figure 11: Setting feature parameters

4.3 Examples

The above-mentioned methodology and algorithms were implemented by using VC++ 2008 and Geometric Modeling Engine CATIA V5R21 with experimental cases. Two implant plates for femur distal and one implant plate for proximal tibia are designed and analyzed in the following cases.

Case1: Design of orthopedic plate for the femoral distal (condylus medialis femoris)

The surface is reconstructed based on the selected region of the bone model as shown in Fig. 12(a). The characteristic curves on surface are extracted including the contours $C1$ and $C2$. The surface feature is parameterized, $P = \{L, W, W_1, W_2, W_3, W_4\}$ as shown in Fig. 12(b), where L is length, W, W_1, W_2, W_3, W_4 are width. The surface shape can be changed by changing feature parameters. The surface is outward moved as shown in Fig. 12(c). According to finite element analysis, the implant plate is divided into several regions, which are thichened by 2 to 3 mm, as shown in Fig. 12(d, e). The volumetric feature is parameterized, $Q = \{L, W, H_{1,} H_{2,} H_{3,} H_3\}$, where L is length, W is width, H_1, H_2, H_3 are the thickness of the regions.

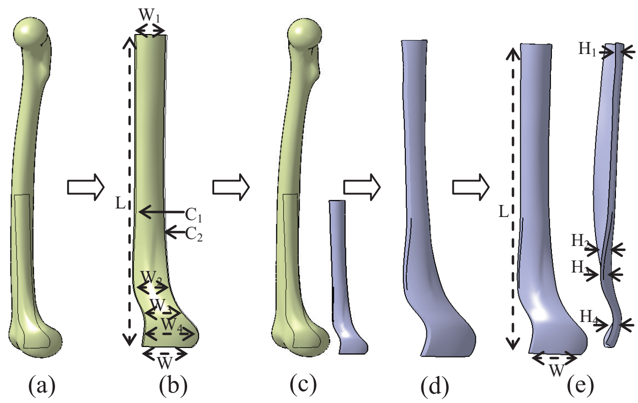


Figure 12: The design flowchart of the implants plate for the femur distal

The individualized implant plate is created via adjusting the mapping relationship μ and the volumetric feature parameters Q, as illustrated in Fig. 13.

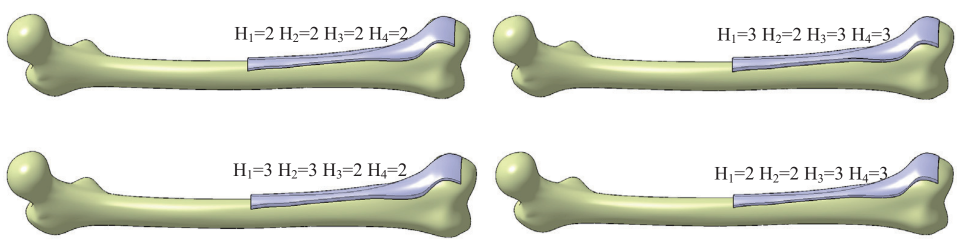


Figure 13: Individualized the plates created by parameters adjustment

Case2: Design of orthopedic plate for the femoral distal (condylus lateralis femoris)

The orthopedic plate is a type of femoral distal plate. It is mainly used for the type of 33B fracture located at femoral distal which is a complexity of joint capsule, ligamenta, muscle and muscle tendon, so fracture block is not easy to reset. To well fix the fracture for individuals, it is necessary to design this type of plate reasonably in shape. Meanwhile, it is important to parameterize the plate.

Fig. 14(a, b) show the fracture of femoral distal and the needed abutted surface of orthopedic plate. Fig. 14(c) shows surface feature parameters and volumetric feature parameters. The surface parameters $P = \{P_{sl}, P_{sw}\}, P_{sl} = \{P_{sl1}, P_{sl2}, P_{sl3}\}, P_{sw} = \{P_{sw1}, P_{sw2}, P_{sw3}\}$; the volumetric feature parameters $Q = \{P_{h1}, P_{h2}, P_{h3}, P_{h4}\}$. In this case, it is convenient to modify the orthopedic plate just by changing any of the above parameters, as shown in Fig. 14(d).

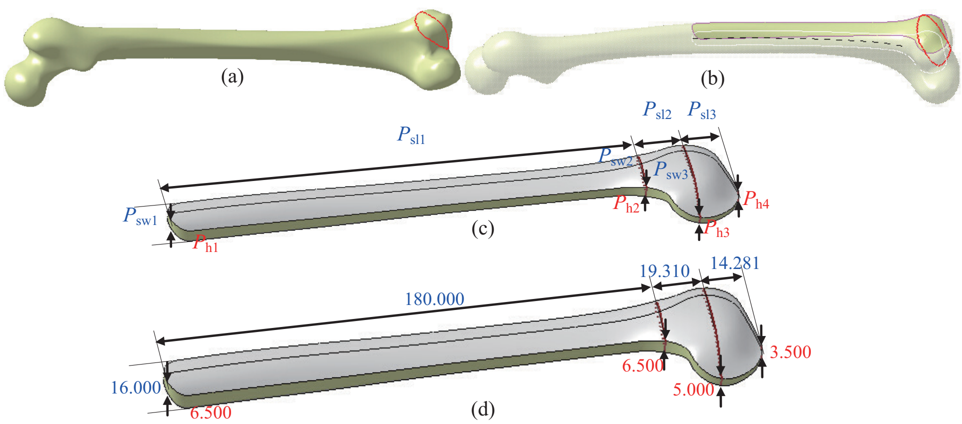


Figure 14: Design of the implants plate for the proximal femur and its parameters adjustment

Case3: Design of orthopedic plate for the proximal tibia

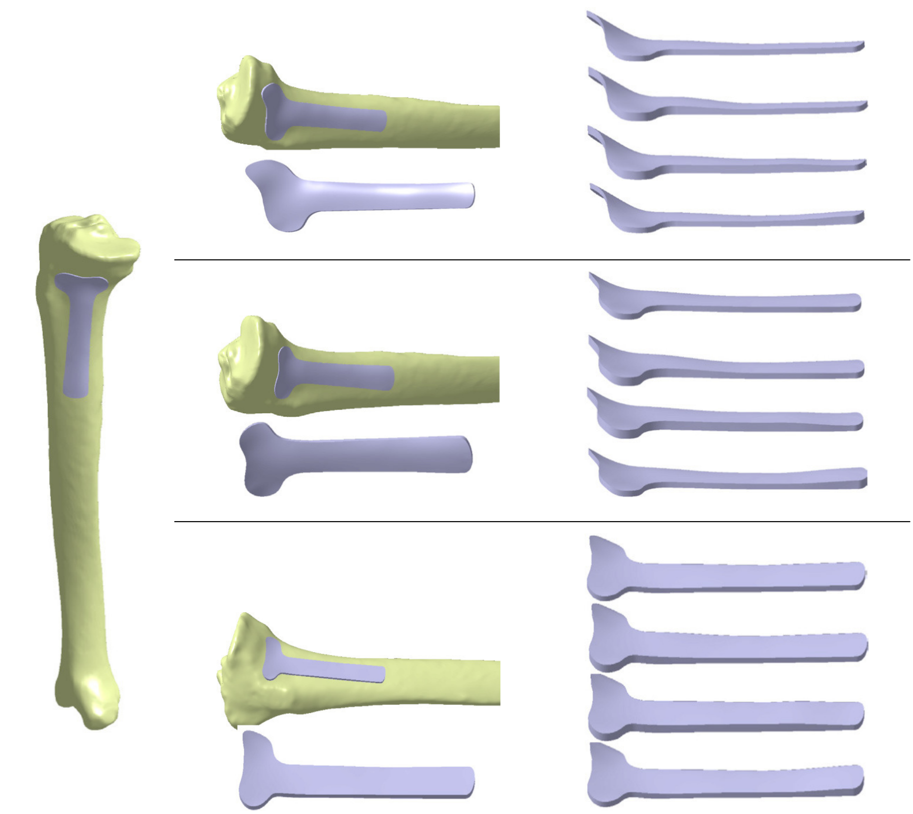
Fig. 15 shows three T types of plates on the proximal tibia. Firstly, the boundary curve and the abutted surface are constructed on the proximal tibia surface model, as shown in Fig. 16(a, b). Some surface parameters are configured on the abutted surface, as shown in Fig. 16(c). Secondly, the plate body is generated by thickening, as shown in Fig. 16(d), and some volumetric parameters are configured.

Table 1 shows a series of plates with different parameter values. On the one hand, the abutted surface can be deformed with different parameter values of surface feature. For example, as illustrated in the left column in Table 1, when we configure surface feature parameters three times with different values, we have three different *T* plates. On the other hand, the plate body can be deformed with different parameter values of volumetric feature. As illustrated in the right column in Table 1, when we configure volumetric feature parameters four times with different values, we have four versions for each type of *T* plate in the left column.

As for the design of orthopedic plate, surface feature and volumetric feature are put forward to apply to the design of orthopedic plate, and it is convenient for users to

Table 1: Plate feature deformation

T type plate	Surface feature deformation with parameters	Volumetric feature deformation with parameters



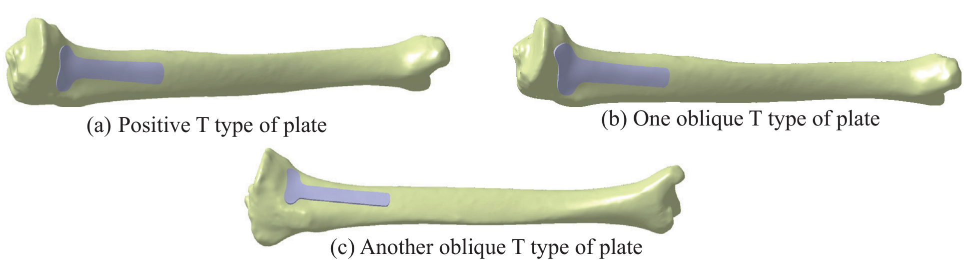
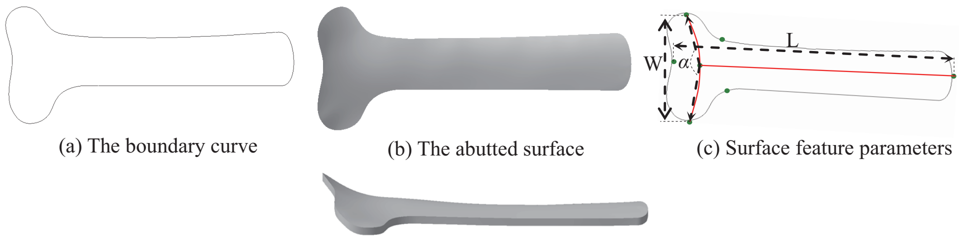


Figure 15: Design of the plates for the proximal tibia

edit and design both individualized and serialized plates. It effectively promotes the quality and efficiency of implants design. This method defines two levels of



(a) The boundary curve
(b) The abutted surface
(c) Surface feature parameters
(d) The volumetric model

Figure 16: The design process of the plates for the proximal tibia

semantics parameters: surface feature and volumetric feature parameters. Once the orthopedic plate is well designed based on feature parameters, it greatly facilitates reuse and avoids starting from scratch. Table 2 shows the comparison between some methods on orthopedic plates design.

Table 2: Comparison of methods of orthopedic plates design

Methods	Bone model	Plate model	Plate parameters	Deformation	Complexity
Arnone	Mesh	Surface	Design parameter	Hard	High
Neto	Mesh	Mesh	No parameter	Normal	Medium
Shen	Point cloud	Surface	No parameter	Hard	High
Ren	Mesh	Mesh	No parameter	Hard	High
This method	Surface	Surface feature	Feature parameter	Easy	Low

5 Conclusion

The quality and efficiency of orthopedic plate design can be greatly improved based on surface feature technology and parameterization in this paper. The main advantages of our method are as following.

1. The orthopedic plate can be rapidly created and conveniently edited with surface feature and volumetric feature.

2. Once a type of orthopedic plate is designed, this type of serialized orthopedic plates can be adaptively generated.

3. A novel approach for extracting and reconstructing abutted surface is put forward, and the reconstructed surface can match well with the fracture bone region.

The method presented in this paper lay foundation for the design of both individualized and serialized orthopedic plates. But the classification of orthopedic plates and its shape analysis are not involved in the paper. Therefore, our future work should focus on the following two aspects: The classification of orthopedic plates, and finite element analysis for different types of orthopedic plates.

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