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## Optimization of Artificial Bone Internal Structure by Topology Optimization: Finite Element Analysis

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# Optimization of Artificial Bone Internal Structure by Topology Optimization: Finite Element Analysis

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**Abstract.** Demand for artificial bone based on titanium metal is huge. The 3-D finite element analysis software is used to simulate the force of the bone model, and the internal structure of the model is optimized by the topology optimization method for material saving. The bone is scanned by computed tomography and then a normal 3-D finite element bone model is built on the computer. Based on the normal model, apply force to the model and determine the pressure distribution of the model, and then an internal structure is optimized by topology optimization method. Four basic type of bone forces which are tension, pressure, bending and torque force are applies to the bone model. The result given by the topology optimization method is a multi-layered ring structure inside the bone model, and in each layer there are certain number of pores. The artificial bone structure proposed in this paper can satisfy the basic force of the bone with using minimum of material.

## 1. Introduction

In the field of orthopedics, bone defects can occur due to various causes such as severe trauma, bone tumors, and osteomyelitis. For patients with bone damage, the pressure on the bone changes due to the overall damage of the bone, which will cause greater pressure on the part or the whole body. Long-term pressure on the damaged part of the bone can cause further damage and also may influence the human tissue in surrounding. For example, femoral head necrosis, Ohzono, et al [1, 7] showed that the femoral head is more likely to collapse when the part of the lesion position at head that often supported by the load.

The replacement of necrotic bone with artificial bone is a medical method currently used in medicine. [13] In biomedical engineering, artificial bone technology is an important medical application field. Titanium alloy recognized as an artificial bone substitute material in the medical field because titanium alloy has the advantages of good corrosion resistance, good elasticity, high strength and high stability, and also has excellent biocompatibility. It does not alter its essence and does not cause allergic reaction to humans. The new bone can be attached to a titanium alloy and can be closely combined with human bone. It is the only metal that has no harm to humans. Therefore, titanium alloy is the most best artificial bone material and has unique therapeutic use.

Topology optimization method is a mathematical method that optimizes the distribution of materials in the given area according to pressure conditions, constraints and performance metrics. It is a type of



structural optimization. In this paper, the bone model is build base on the bone data of CT scan. The finite element analysis software is utilize to analyse the force and topology, and the internal structure of the model is optimize. [15, 16] The final result will provide a novel idea for designing artificial bone.

## 2. Methods

### 2.1. Establish a 3-D finite element model of bone

We obtain data from a CT scan of the normal bones from the CT database of the local hospital. A total of 513 CT images were obtained at 0.70mm intervals in the transverse plane with GE Light Speed VCT (General Electric, Milwaukee, WI, USA) at a resolution of 512 x 512 pixels. All data are transferred into the computer and the model is optimize by using SolidWorks software. Finally, the 3D finite element model is import into the Hyper Works software.

In this paper, we divide the bone model into internal and external areas. We set the thickness of the model boundary surface by 5% as the external areas, and the remaining part is the internal areas. The external areas are not affect during topology optimization process. The material using for this model is titanium metal, which uses the material properties of T4. The properties are elastic modulus of 100 GPa, density of 4500 kg/m<sup>3</sup> and Poisson's ratio of 0.33.

### 2.2. Boundary conditions and forces

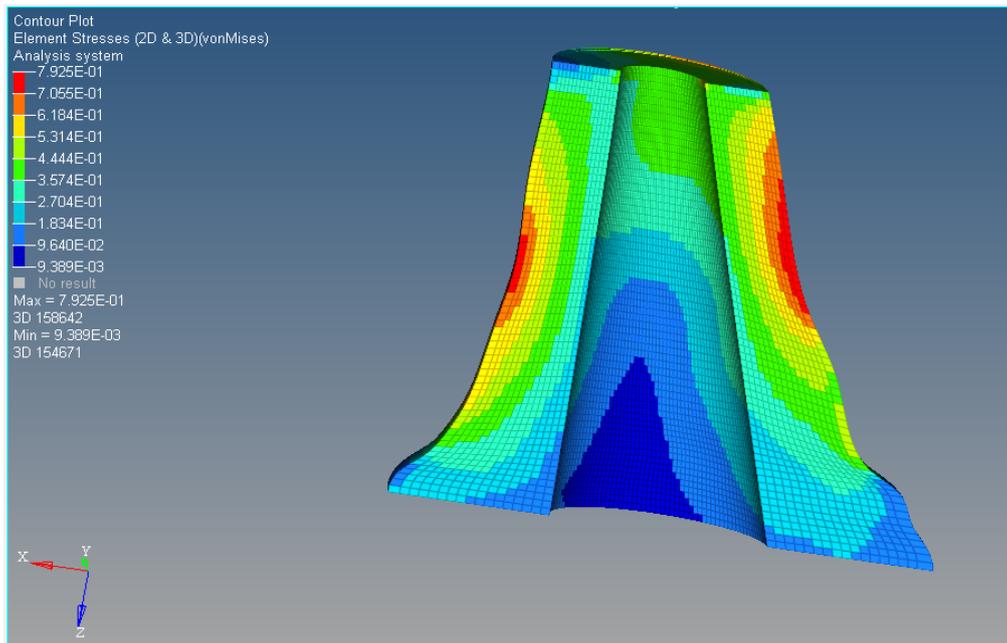
Because the force of the bone is more complex, in this paper, we selects several forces that have the greatest influence on the pressure of the bone as the force analysis of topology optimization method. First add a fix at the bottom of the bone, then create a point above the bone and apply force, and a rigid connection between the point and the upper area of the bone to connect the point to the upper area of the bone. When a load is added to a point, all forces can be applied to the upper area of the bone. In this paper, we set four type forces for the bone model, 700N pressure above the bone, and the two different directions of the bending force 500N, 300N and the torque force 150Nm.

All calculations are done by using hyper work software. The data will show the force distribution of the bone and the optimize internal structure.

## 3. Result

### 3.1. Pressure analysis

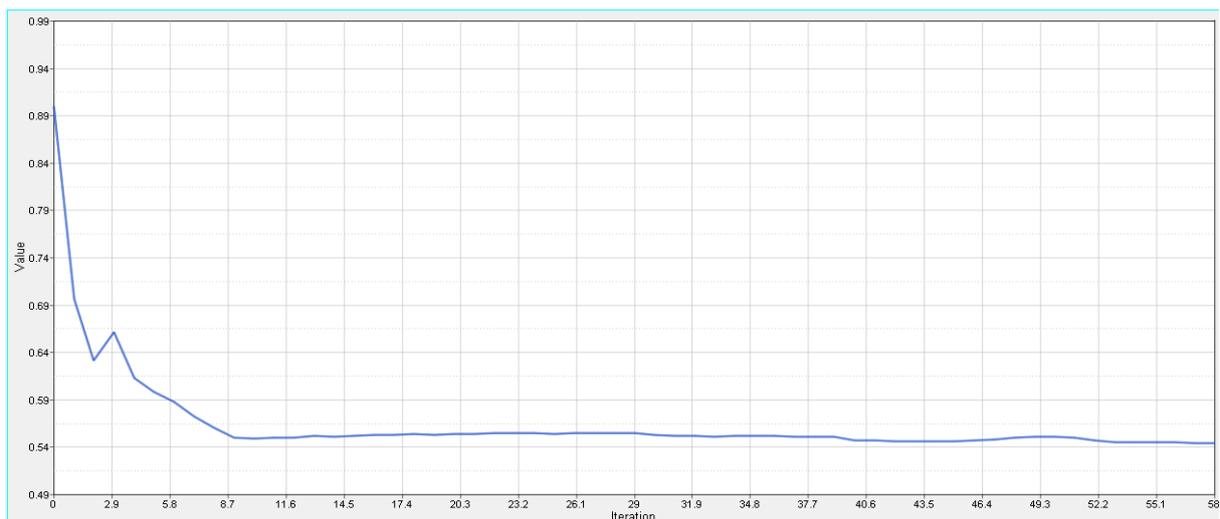
In this paper, the bone model is built base on a CT scan of normal bone. Structural optimization of the internal areas of the bone is the focus of this paper. The force of the bone is complex. We select the four forces that have the most influence on the bone in the actual situation (pressure 700N, bending force 500N, 300N, torque 150Nm). As showed in Figure 1, the pressure distribution of the bone is characterized by the largest pressure between the upper and the middle of the bone and the minimum pressure at the bottom.



**Figure 1.** The pressure distribution of the bone model under different pressures (pressure 700N, bending force 500N, 300N, torque 150Nm).

### 3.2. Optimization Results

In the Hyperwork software, topology optimization is performed on the inner areas of the bone model. As showed in Figure 2, after several iterations of the bone model, the ultimate optimization result is that the internal structure of the bone model has a multi-layer structure, and the internal structure is optimized to 0.54. Since topology optimization method eliminates unstressed areas or areas with less pressure during the iterative process, this structure is the optimal result of this topology optimization.

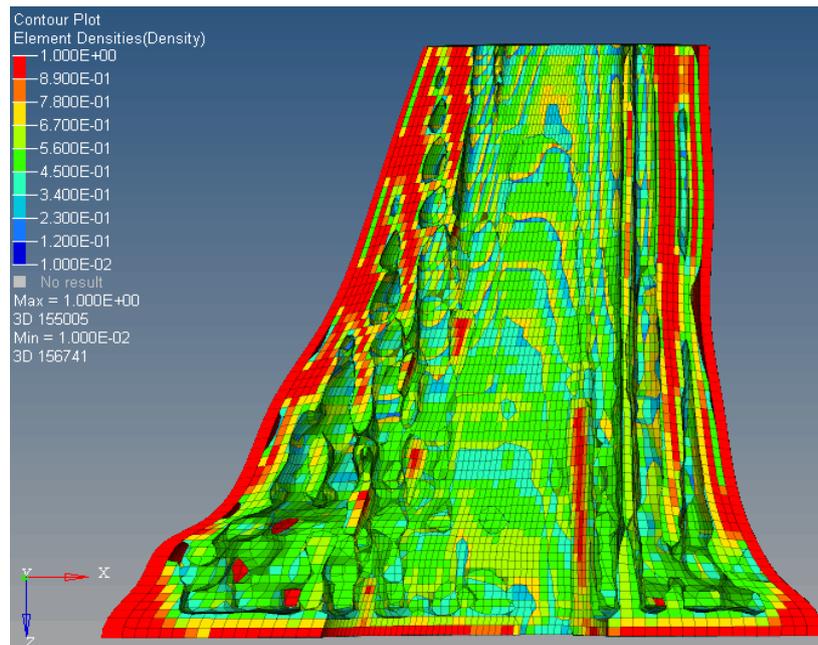


**Figure 2.** The result of the model after 58 iterations of topology optimization.

### 3.3. New structure

The optimization results in this paper provide us with a new design idea. This new structure has the same mechanical properties as traditional artificial bone. According to the optimization results of this paper, the model can be designed with reference to this result when designing the internal structure of

the simulated bone. As showed in Figure 3, the internal structure of the artificial bone is designed as a multi-layered ring structure, and each layer has a certain number of pores. In the actual design process, we also need to consider the effect of simulate bone on postoperative recovery of patients. The porous structure is to facilitate the growth of bone cells in the artificial bone portion, thereby enhancing the fixation, which is also consistent with the internal porous structure of human bone tissue. In the case where the annular multilayer structure is maintained, a porous structure is added to a part of the external areas, and a porous structure is added to the corresponding inner areas. The forces before and after the bone model remain unchanged.



**Figure 3.** The final optimization of the bone model results in a four-layered annular structure, each of which can have a certain number of pores.

#### 4. Conclusion

This paper provides a new artificial bone internal structure scheme that combines the characteristics of the current internal grid structure. The multi-layered annular structure satisfies the mechanical properties of the artificial bone and sales materials. The force of the bone is more complex. Because the hardness of the titanium itself exceeds the bone, some of the forces with less impact can be neglected, and only four of the most influential forces are added. Studies have shown that the pore structure inside the artificial bone contributes to the postoperative recovery of the patient, and the number, size and shape of the pores affect the mechanical properties of the artificial bone. The internal optimization area of the bone model in this paper is a multi-layered ring structure. This structure is a pressured area. Between each layer we can add porous materials, connect them through the pores on each layer, and change the corresponding part in the external area to a porous structure, so that the bone cells can grow in the artificial bone and artificial bone fixed on the bone.

The research in this paper is build on the simulation of computer software. There are certain limitations. In terms of bone pressure, the force analysis simulate in the software is not complicate in the actual pressure of the bone. This design structure meets the expect requirements, but it still needs to be continuously optimized and improved according to the actual situation. More work is need in order to improve this work. In short, this structure provides a new design idea for us to design artificial bone.

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