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Design of Complex Bone Internal Structure using Topology Optimization with Perimeter Control

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Abstract

Large facial bone loss usually requires patient-specific bone implants to restore the structural integrity and functionality that also affects the appearance of each patient. Titanium alloys (e.g., Ti-6Al-4V) are typically used in the interfacial porous coatings between the implant and the surrounding bone to promote stability. There exists a property mismatch between the two that in general leads to complications such as stress-shielding. This biomechanical discrepancy is a hurdle in the design of bone replacements. To alleviate the mismatch, the internal structure of the bone replacements should match that of the bone. Topology optimization has proven to be a good technique for designing bone replacements. However, the complex internal structure of the bone is difficult to mimic using conventional topology optimization methods without additional restrictions. In this work, the complex bone internal structure is recovered using a perimeter control based topology optimization approach. By restricting the solution space by means of the perimeter, the intricate design complexity of bones can be achieved. Three different bone regions with well-known physiological loadings are selected to illustrate the efficacy of the method and design the internal structural configurations. Additionally, we found that the target perimeter value and the pattern of the initial distribution play a vital role in obtaining the natural curvatures in the bone internal structures as well as avoiding excessive island patterns.

Keywords: Bone, Internal Structure, Topology optimization, Perimeter control

1. Introduction

The internal architecture of bone is complex and remodels continuously. The stress trajectories and material distribution in human bone have been studied extensively. Also, a lot of efforts have been invested in understanding the evolution of the internal architecture of bone and their physiological loading [1, 2]. Under the assumption that it achieves maximum mechanical stiffness with minimum mass, bone is considered to be structurally optimized where it adapts to long-term

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