OPTIMIZATION OF TITANIUM SPINAL CAGES TO MAXIMIZE SYNTHETIC GRAFT CONTENT IN COMPOSITE IMPLANTS

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Introduction

Spinal fusion is the current gold standard for treating patients with degenerative disc disease [1]. Titanium alloys are commonly used to make cages for spinal fusion, which are used to keep the disc height stable while the vertebrae fuse together. Materials such as morselized bone may also be added to the cage to enhance its bioactivity. A monetite-based calcium phosphate (MCP) in combination with titanium has demonstrated potentially osteoinductive properties [2], and may be a synthetic alternative to bone graft. Maximizing the ratio of MCP to titanium could be desirable to maximize bone ingrowth and fusion. Further, the calcium phosphate can be incorporated into the cage and stored ahead of surgery. However, due to the brittle nature of MCPs, they cannot be incorporated in current implants effectively. The aim of this study was to topologically optimize titanium cervical spine implants to incorporate a bioactive but mechanically weak material such as MCP.

Methods

An outer geometry was established based on the shape of cervical vertebrae, with a height representing a typical distance between two cervical vertebrae in a healthy spine, as recommended by ASTM F2077. All quasi-static simulations were performed with Ansys (2020).

It was assumed that the Ti-6Al-4V material would exhibit isotropic behaviour and had a Poisson's ratio of $v = 0.3$. The elastic modulus was estimated from tensile testing of additively manufactured samples (power bed fusion with laser beam using Osprey titanium powder, Sandvik AB, Sweden, and an EOS 100, EOS GmbH, Germany), according to ASTM E8/E8M, as this would be the future method for producing the titanium cages. Samples were printed in both the vertical and horizontal direction, to test for isotropy in the printed material.

In the simulations, the bottom and top faces were bonded to stiff plates. Four different loading scenarios were investigated: flexion-extension, axial rotation, and a lateral bending with a compression preload [3]. Compression-shear was also included as part of the ASTM F2077.

To optimize global stiffness, an algorithm based on [4] was applied with an effective stress limit of 0.35 GPa (corresponding to the estimated fatigue life of Ti-6Al-4V [5]). Feature sizes were also limited to 1.5-2 mm to construct a semi-porous cage. The optimization problem was subjected to all the loading scenarios sequentially.

Results

The titanium tensile tests showed no significant difference between the different printing directions, with estimated elastic moduli of 112.5 ±4.9 GPa and yield stress of 1.17 ± 0.05 GPa. These values are comparable to the material property datasheet.

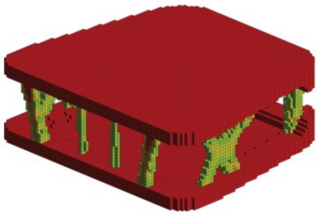

Fig. 1 Optimized design of a spinal cage before post-processing.

The resulting geometry from the topology optimization portrayed a structure with a large cavity where synthetic graft can be placed (Fig. 1). The final optimized geometry had an 85% volume reduction and a maximum effective stress of about 160 MPa in all loading scenarios.

Discussion

Preliminary cage designs, were manufactured to investigate the structure's mechanical behaviour under different load cases. The results imply that it is possible to produce a cage with a substantial volume for calcium phosphate incorporation. However, the cage requires a feature to allow bone growth from both endplates. Future work includes post-processing, experimental validation using ASTM F2077, and the addition of more complex geometrical features to enable clinical implementation.

References

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