

3D printed Ti6Al4V hybrid solid mesh structure for customized implant to treat bone cancer

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Disclosures: There is nothing to disclose.

INTRODUCTION: Bone replacement implants manufactured by electron beam melting have been widely studied for use in bone tumor treatment. In this application, a hybrid structure implant with a combination of solid and lattice structures guarantees strong adhesion between bone and soft tissues. This hybrid implant must exhibit adequate mechanical performance so as to satisfy the safety criteria considering repeated weight loading during the patient's lifetime. With a low volume of a clinical case, various shape and volume combinations, including both solid and lattice structures, should be evaluated to provide guidelines for implant design.

METHODS: The present study entailed mechanical and microstructural analyses for Ti-6Al-4V solid-mesh hybrid structures produced by electron beam melting (EBM). While these studies have been conducted on specimens with cross-sectional symmetry, in actual surgical cases, implants have complex surfaces with an asymmetric section, as shown in Figure 1, for the purpose of ensuring sufficient mechanical strength and avoiding damage major neurovascular structure. Thus, studies on such hybrid implants, including pizza types (P-type) and shell types (S-type), should be carried out. Different types of hybrid structures with various volume fractions of lattice structures were compared using experimental and computational analyses (FEA, finite element analysis). The FEA results were validated using experimental data, and after the tensile test, microstructure analysis of the cross-sectional area of the specimens was conducted.

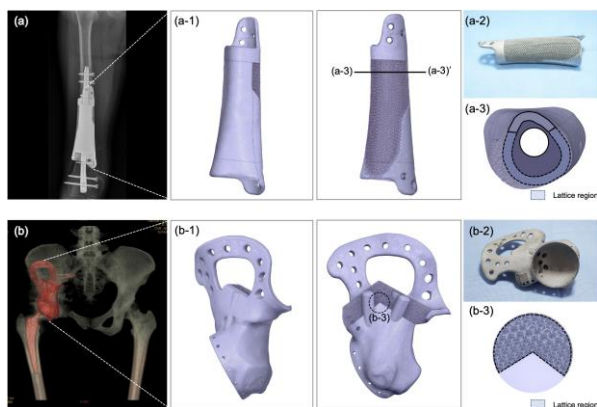
RESULTS SECTION: The mechanical behavior of Ti-6Al-4V specimens with the proposed hybrid structures produced by EBM was tested and simulated. We compared two types of hybrid structures and validated the FEA results with the experimental data. Based on the FEA results, the maximum von Mises stress increases as the volume fraction of the lattice structure increases. Analysis of the tensile test also showed that the mechanical performance tends to decrease as the volume fraction of the lattice structures increases. The fractography results showed that the tensile strength increases with increasing volume fraction of the solid region composed of stages 1 and 2, regardless of the specimen type. In a tensile test, the performance of the shell design was superior to that of the P-type with the same volume fraction of lattice structures. The P- and S-types were analyzed using electron backscatter diffraction (EBSD) results and fractographic analysis. After the tensile test, the EBSD results for the cross-sectional area of the S-type specimen revealed that the lath width was finer in the mesh region than in the solid region. In contrast, the P-type specimen's lath widths were similar. Fine acicular α' martensite observed in the S-type mesh region is generated at high-temperature gradients near the rim and high cooling rates of the mesh structures, thereby increasing the tensile strength of the specimen. In addition, the results of the fractographic analysis of P- and S-type specimens with the same mesh volume fraction indicate that the high strength of the S-type specimen was achieved by the large volume fraction of the stage 1 area, where deep and clear dimples were observed.

DISCUSSION: These results demonstrate how hybrid implants may be designed to improve clinical outcomes by using patient-specific orthopedic implants with optimized volume fraction of the lattice structure, allowing for effective enhancement of mechanical performance as well as optimized design for bone cell ingrowth.

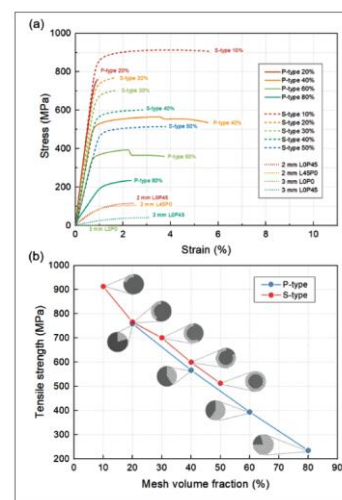
SIGNIFICANCE/CLINICAL RELEVANCE:

In orthopedic applications, the investigation of Ti-6Al-4V solid-mesh hybrid structures produced by electron beam melting (EBM) reveals that the mechanical performance of such implants, crucial for bone tumor treatment, is influenced by the volume fraction of lattice structures. The superior tensile strength observed in shell-type (S-type) specimens with a large volume fraction of stage 1 area suggests the potential for optimizing patient-specific orthopedic implants, emphasizing the importance of tailored lattice structure configurations for enhanced clinical outcomes in bone cell ingrowth.

IMAGES AND TABLES:



(a) Shell type, (b) Pizza type



(a) Stress-strain curves, (b) tensile strength by mesh volume fraction