Architectured material with gradient mechanical properties 3D printed using low-cost LCD printing via a two-step curing process to reproduce the heterogeneous mechanical behaviour of bones.

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Abstract

3D-printed architectured materials have been attracting growing interest in recent years in the development of bone substitutes. The main objective of this research is to design structures with mechanical properties similar to those of natural bone in order to promote osseointegration and limit bone-implant mechanical mismatch . Among the various approaches, structures based on triply periodic minimal surfaces (TPMS) are widely studied. Some teams have already introduced a coarse porosity gradient between the ‘cortical’ and ‘trabecular’ parts of implants in order to reproduce the natural heterogeneity of bone architecture. However, these gradients are often defined by simplified analytical functions that do not accurately reflect the local mechanical variations within bones. In this context, we propose a new method for generating TPMS architectures based on a mapping of bone local mechanical properties rather than on a pre-established analytical gradient. To optimize resolution, cost and printing time, we use LCD 3D printing . This technique offers considerable advantages in these three areas, but it generally requires post-treatment in a UV chamber. However, due to the low penetration of UV light into the material, this post-treatment can lead to local inhomogeneities in polymerization and, consequently, in mechanical properties. The chosen material to test this approach is 3D printed using a two-step curing technique, which produces a controlled homogeneous mechanical properties of the polymer materials allowing us to produce architectured samples with bone-like heterogeneous mechanical properties. The parameters of this technique have been studied in depth using macroscopic mechanical tests on architectures of various sizes, as well as nanoindentation tests to characterize local properties. The degree of polymer conversion was also analyzed using Fourier transform infrared spectroscopy (FTIR). These studies have made it possible to optimize the printing process and demonstrate the potential to reproduce the overall mechanical behavior of bone (Young's modulus and strength) using an architectured material based on local mapping of mechanical properties obtained through clinical quantitative imaging. TPMS biomaterials with density gradients represent a significant advance in the field of tissue engineering. Their ability to faithfully reproduce the structural and mechanical characteristics of natural bone increases their potential for osseointegration and effective bone regeneration. By incorporating complex porosity gradients based on patient-specific mapping rather than general analytical functions, these architectures better meet the varied mechanical and biological requirements of bone repair. The development of a two-step curing process, usable with consumer 3D printers, is also a major advance, as it limits problems of incomplete polymerization and reduces production costs.

Keywords:

Bone Substitute Bone Model 3D Printing Triply Periodic Minimal Surfaces Porosity Gradient Osteoporosis Bone metastasis