MODELING MECHANICS OF 3D PRINTED CERAMIC BONE SUBSTITUTE IMPLANTS TOWARDS PERSONALIZED DEVICES

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Background

3D printing is an emergent manufacturing technology recently being applied in the medical field for the development of custom bone prostheses and scaffolds.
Among the several Additive Manufacturing technologies, 3D printing through vat PhotoPolymerization (VPP) is a lithography-based approach that may achieve the highest spatial resolution (less than 50 m) among currently known additive manufacturing strategies. Compared to metallic and polymeric biomaterials, calcium phosphate ceramics like hydroxyapatite (HA) tricalcium phosphate and biphasic calcium phosphate implants show strong osteogenic ability without adverse reaction. HA is of particular relevance since HA bone replacements have a similar initial mechanical characteristic to cancellous bone, although this can decline by 30-40% in situ after several months after implantation. Through VPP, HA can be used to create devices with sophisticated microarchitectural elements that have great resolution [1]. The ability to customize the device to match the patient's individual needs makes 3D printing technology a game changer in the design process of such sophisticated biomedical equipment.

Recent Advances

The design of biomechanically reliable bone scaffolds necessitates a high-fidelity manufacturing process and a precise understanding of the mechanical properties of the constituent material. To this purpose, geometric fidelity analyses, mechanical characterization of miniaturized samples [2] and, eventually, micro computed tomography based finite element models are currently being generated [3,4]. Elastic modulus, fracture toughness and tensile strength are dependent not only on the manufacturing process parameters, but also on the sample size and consequently on average intrinsic defects occurring during the manufacturing process and thermal treatments.

Future directions

Developing characterisation methods for ceramic materials and microstructured bone scaffolds that take manufacturing parameters and characteristic size into consideration is a vital step in setting the groundwork for an innovative approach to more personalized devices. Indeed, a successful industry transition to this new design approach necessitates the integration of technology, concurrent multidisciplinary collaboration, and a robust quality management system. To bring innovation into the clinical practice of bone substitute devices, innovative multidisciplinary design optimization approaches integrating clinical image data analysis, high fidelity VPP printing process, patient-specific multiscale models, biomechanical and mechanobiological design, and immersive reality technologies for surgical planning must be implemented.

Pasquale Vena is currently Associate Professor at the Department of Chemistry, Materials and Chemical Engineering, Politecnico di Milano, Italy. He obtained his PhD in Strcutural Engineering at the Politecnico di Milano in 1998. His current research is carried out at the Laboratory of Biological Structures at Politecnico di Milano and focuses on the mechanics of biomaterials and tissues with particular emphasis on micro-scale modeling and experiment on bone tissue engineering scaffolds. He is an author of more than 100 publications in peer- reviewed journals, former member of the scientific committee of the ESB2021 conference and is organizers of different mini-symposia at international conferences.

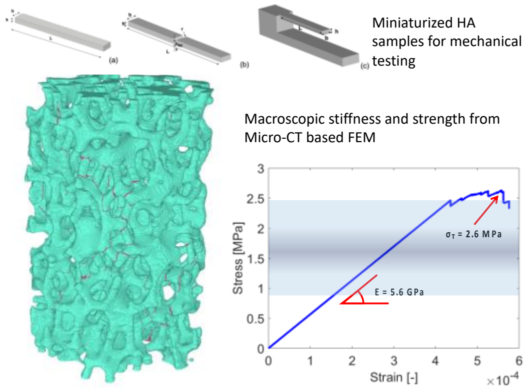

Figure 1: Sketch of miniaturized sample and micro-CT based FEM mechanical analysis of VPP HAP scaffolds.

References

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2. Gastaldi et al. J Mech Behav Biomed, 112, 2020
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