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Abstract

Designing 3D printed ceramic lattice structures for osseointegrative implants

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Modern 3D printing techniques make it possible to produce implants using high-performance ceramic material. Ceramic materials such as zirconia (ZrO_2) have some advantages over previously used materials such as titanium, as they possess high strength and are especially good for bone integration. To have optimal osseointegrative /osteoconductive properties it is helpful to produce a lattice structure with pores and a large surface area, rather than a bulk ceramic part, which can be done utilizing additive manufacturing. Lattice structures allow bone cells to grow well into an implant that has a hollow interior and can lead to a reduction of the high stiffness to a level similar to bone material to avoid stress shielding. The aim of this study was to investigate different types of lattices with respect to their mechanical properties (compression, tension, shear, bending). The results will help to determine the most appropriate lattice designs for future implants.

Seven different graph-based lattice types, each with 80% porosity, were designed, simulated by finite element analysis, and up to 25 ZrO_2 specimens were fabricated using stereolithography and thermal post-processing. The design geometries of the specimens were partly inspired by the literature, where this microarchitecture has already been investigated for osseointegrativity and osseoconductivity. In addition to regular lattice geometries a Voronoi lattice was included with an average pore size comparable to the other structures. All these specimens were tested in compression, tension, shear, and flexure to determine their Young's modulus and fracture strength. Weibull statistics were used to determine the fracture risk of each structure, depending on the applied stress. Although all the structures had the same porosity and therefore the same weight, the surface area and mechanical stability varied. The measured compression elasticity for the different structures varied in the range of 5 GPa to 26 GPa, which corresponds to the stiffness range of bone material. Since slight variations in geometry occur during fabrication, the finite element simulation does not exactly match the measurement results, but gives a good estimate (differences <5 GPa) of what to expect from the structure. The average breaking strength, derived from Weibull statistics, under compressive load ranged from 80 MPa to 550 MPa. Its value was lower for the other load cases, with lowest values ranging from 3 MPa to 8.4 MPa for shear load.

The study of these lattices shows that the stability is different depending on the loading case, but the osseointegration property, according to the literature, would be very similar. The knowledge of the different structures allows the use of the most appropriate lattice structure for the biomechanical load when designing the implant. Exchanging bulk material with sufficiently stable lattice structures, can result in an implant with better overall osseointegration/osteoconductive properties at the cost of lower breaking strength. Furthermore, with the results of this investigation, it is easy to infer the stability of similar lattice structures but with different parameters, such as pore size or beam thickness. Such changes may require a reconsideration of the osseointegrative properties of the architecture, but greatly expand the options for additive manufacturing applications.

AUTHOR'S STATEMENT

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