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Abstract

Topology optimization and high cycle fatigue modeling in additively manufactured dental implants

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We introduce an innovative and efficient methodology for improving the longevity and performance of dental implants while minimizing stress-shielding. This is achieved by modifying the internal structure of the implant using two distinct strategies: topology optimization [1] and Triply Periodic Minimal Surface (TPMS) lattices. The density-based topology optimization involves a material model for hardening. TPMS Lattices are complex, repeating structures that mimic natural geometries found in biological systems. These lattices can be engineered to provide optimal mechanical properties, such as strength and flexibility, while also promoting bone-like structure due to their porous nature. Both strategies are analyzed using an ANSYS model with material parameters derived from mechanical tests of additively manufactured Ti-6Al-4V.

In addition, we present a novel and efficient methodology for modeling fatigue induced by damage and plasticity, based on the extended Hamilton principle for dissipative processes [2,3]. This method leverages the Hamilton principle, which is a fundamental principle in classical mechanics. Traditional cycle-by-cycle simulations for high-cycle fatigue are computationally intensive and inefficient. Using this principle, we develop a simulation technique that utilizes the maximum amplitude of loads, rather than the exact profile of each individual load cycle. This significantly reduces computational time and required resources. By changing the time space within the simulations, it becomes possible to track force reactions over extended periods efficiently. During postprocessing, hysteresis loops (which represent energy dissipation in materials) and S-N curves (which relate the cyclic stress amplitude to the number of cycles to failure) can be derived without losing accuracy.

This approach ensures robust and accurate simulations of high-cycle fatigue, making it possible to predict the long-term stability of the implants. The high-cycle fatigue material model shows that the topologically optimized structures exhibit no fatigue, indicating their potential for long-term use in dental implants.

AUTHOR'S STATEMENT

Authors state no conflict of interest. Animal models: n./a. Informed consent has been obtained from all individuals included in this study.
Ethical approval: n./a. Acknowledgments: DFG FOR5250, Project number: 449916462, TP-Z: Mechanism-based characterization and modeling of permanent and bioresorbable implants with tailored functionality based on innovative in vivo, in vitro and in silico methods. TP-7: In silico design of implants based on a multiscale approach.

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