Surface Design in Additive Manufacturing Medical Implants

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Abstract

Bone–implant stability can be improved by fabricating porous titanium implant surfaces using additive manufacturing (AM) with the right porosity and size. In order to enhance the effectiveness of bone ingrowth and the strength of the interfacial bonded, a thorough understanding of the biomechanical properties of porous (lattice) implants is essential. The findings of this study call for the development of a brand-new type of lattice implant with a lattice that provides a favorable physiological environment for bone ingrowth and strengthens the bond between the implant and bone.

Introduction

To improve bone cell growth capacity, a unit (1mm3 cube) YM lattice with 65 percent porosity and an average pore size of 750 m was constructed as a 3D spherical structure with multiple corners for accepting cell clustering, transporting fluids, nutrients, and removing impurities between these interconnected through-holes. The implant-bone interface micro mechanical behavior, including lattice pillars, bone within and around lattices for four distinct lattice types—YMU, YMR (YM lattice without deformation and with 30% deformation), DU, and DR—was investigated using the finite element (FE) sub-modeling method. A Ti6Al4V AM was used to select, fabricate, and implant the DU and YMR lattice implants (each n = 5) into the distal right femurs of ten rabbits for eight weeks to observe the results. After the rabbits were killed, the interface tensile bonded strength test was carried out. After surgery, none of the rabbits' lattice implants slipped. This backs up the radiographs from the surgery. The bonded force and strength of the YMR lattice were found to be significantly higher than those of the DU lattice in the tests. The comparing values were 113.14 ± 21.96 N and 5.39 ± 1.04 MPa for the YMR cross section and 41.41 ± 15.32 N and 1.97 ± 0.73 MPa for the DU grid. An YMR lattice with a suitable bone ingrowth environment and an interfacial bond strength test for the AM medical implant's surface porous design was proposed in this study.

The osseointegration process, implant fixation capacity, and surrounding bone healing can all be affected by surface treatment at the bone-titanium alloy implant interface [1-3]. In order to give the titanium alloy an irregular (roughness) surface with increasing contact area between the living bone and the implant in order to enhance bone osseointegration, a number of surface treatment techniques, including chemical (acid-etching) and mechanical (sintered bead-bonded and grit-blasting), or a combination of the two, were proposed to accompany conventional machining, cutting, or milling. In any case, the surface harshness profundity created by these strategies is restricted. To avoid the stress shielding effect caused by the high elastic modulus implant, this method can only perform bone osseointegration, but it cannot accomplish the goal of bone ingrowth [4].

Computer-aided design (CAD) models can now be used to build complex 3D structures using metal additive manufacturing (AM) techniques. The difficulties of creating a porous (lattice) surface coating on a dense titanium and porous titanium body can be solved using AM techniques. Numerous studies showed that porous titanium implants made with AM can improve bone–implant stability by allowing for sufficient bone ingrowth. It is common knowledge that pore design parameters such as porosity, morphology (type of lattice), size, and distribution have a significant impact on the biocompatibility and compatibility of the mechanical structure. The most important objective for pore design parameters that are applied to the bone-implant interface

is to achieve early osseointegration in order to produce an implant with strong stabilization [5-7]. Hara et al.'s research furthermore, Li et al. indicated that AM-produced porous titanium-alloy implants with a porosity of 60–70 percent and a pore size of less than 800 m provided biologically active and mechanically stable surfaces for implant fixation to bone.

Osteocyte mechanical behavior is linked to bone ingrowth efficiency and interfacial bond strength. There is a lack of research on the pore type biomechanical analysis (lattice type) for AM-produced bone-implant interfaces. The ability of bone tissue to osseointegrate at the bone-implant interface can be assessed using strain. Micro strains of a moderate magnitude of 1000–3000 have been shown experimentally to enhance the osseointegration process by promoting local bone formation [8]. For long-term osseointegration, titanium alloy implant surfaces with the appropriate pore type (lattice type) can create a more physiologically favorable mechanical environment for adjacent and ingrown bone. Lattice bone ingrowth efficiency can be improved by understanding how various metal lattice loads are transferred to the surrounding bone tissue at the bone-implant interface.

The typical finite element (FE) approach is difficult to apply to the bone-implant interface in order to obtain detailed mechanical information because the metal lattice/surrounding bone dimensions are much smaller than those of the global configuration. Despite the fact that FE analysis is a compensative method for investigating the biomechanics of the bone and implant interface, Sub-modeling, on the other hand, uses a local micro model with boundary conditions that are based on the pre-analyzed global model results to determine the local mechanical responses to determine precise and detailed solutions in particular areas [9-10]. FE sub-modeling analysis has been used to extensively investigate and resolve issues in biomechanical fields to observe the local mechanical behavior of multi-scale objects. Microcrack growth in dental post-restoration, implant micro surface abrasion analysis], and adhesive mechanical behavior between enamel and orthodontic basket were all studied with this advanced FE

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technique. These studies proved that FE sub-modeling analysis can be used to investigate micromechanical behavior and that it is a reliable simulation method for resolving multi-scale mechanical issues that cannot be solved by traditional in vitro simulation or experiment.

In order to improve bone ingrowth capability, this study develops a novel lattice type that may be more suitable for AM bone-implant interface applications. In order to create a brand-new lattice, FE sub-modeling analysis was used to comprehend the mechanical behavior of the bone-implant interface under micro-strain. In order to carry out the process of bone ingrowth, porous titanium alloy implants made with new Diamond lattices were inserted into the lateral femurs of rabbits for an eight-week period. To confirm the FE sub-modeling analysis result, interfacial tensile bonded strength tests between various lattices and bone tissues were carried out.

The fact that only strain was used as the bone remodeling index in the FE sub-model analysis was the study's only drawback. Since strain energy and other indicators were recently proposed, the analyzed results were only used as a reference for trends. In the in vivo animal experiments, there was no special control over the rabbits' activities (movement direction or jumping times) after surgery. The FE sub-modeling analysis assumed load and boundary conditions, so simulation and animal experiment results cannot be directly validated. Because the tensile bonded strength test can directly indicate the normal bonded lattice strength and the surrounding bones after osseointegration, it was only used to understand the mechanical performance of the lattice implant and surrounding bone. Only the shear force between the lattice interface and the bone contact surface can be determined in comparison to the majority of other interfacial strength tests, such as the pull-out test. The ability of this shear test to check the normal strength of the connection between the bone and the lattice is limited. As a result, the purpose of our research was to develop a normal tensile bonded test in order to ascertain the strength in the normal direction—which may be the most significant factor in determining the osseointegration effect following surgery. To support the findings of this study, another

limitation ought to be the need to further enhance the method as well as the number in the histomorphometrical evaluation.

Declaration of Competing Interest

The Authors declare that they have no conflict of interest.

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