Design and Optimization of Triply Periodic Minimal Surfaces based Porous Scaffolds for Bone Applications: A Conceptual Prosthetic Design for Restoration of Large Bone Defects

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by

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Conclusions and Recommendations for Future Work

Conclusions

In the present work, TPMS based porous unit cell is developed by using marching cube algorithm. An efficient technique is presented to convert STL models into solid models to reduce the redundancy of STL models used in the FEA process. Consequently, the method has shown the potential for robust parameterization of these structures which are essentially required when adopting finite element analysis to evaluate the mechanical and fluidic characteristics of scaffolds based on these porous structures.

Due to finite element approach adopted, this method could be the comprehensive basis for the analysis any type of complex porous structures. The structural design and analysis of the TPMS-based porous scaffold is an important factor for determining the pre-clinical performance of the implant to treat segmental bone defects. Besides, reducing the effective elastic modulus of Ti6Al4V based lattice structures, the work also revealed that by using porous structures the fluid property can also be tuned according to the specific requirement. Additionally, it was shown that morphological properties (pore shape and size, strut thickness, and porosity) of porous scaffolds are the basic controlling parameters that greatly influence their overall performance. However, an optimum balance between the structural-mechanical and fluid properties to obtain complex porous structures and their integrity at specific locations is challenging.

In contribution to this, the present study proposed the development of 3D porous scaffolds of TPMS based Primitive, Gyroid, Diamond and IWP structures with porosities ranging from 50% to 90%. Morphological analysis was performed to evaluate the mechanical behavior. The results revealed the correlation of porosity with pore size and strut thickness and developed a relationship in which any level of porous structures can be conveniently modeled on the following strut thickness. TPMS-based porous structures modeled by Ti6Al4V material exhibited low effective modulus, coordinating with Young's modulus range of human cortical and cancellous bone. The results revealed that P demonstrated overall superior properties, in terms of compressive strength, and G demonstrated superior properties, in terms of effective elastic modulus while keeping in view of fluidic and morphological properties and, therefore, both could be used for patient-specific scaffolds, depending on the parameters favorable for the anatomical locations of bone.

Intentional large segmental defect was created on the femur bone and an anatomically matched scaffold was developed to evaltuate the functionality assessment. The outcomes of stress transfer characteristics have shown the potential that porous structures effectively reduced the stress shielding phenomenon which suggests that TPMS-based porous structures have the potential to reduce the stiffness mismatch between the bone-implant interfaces. A further extensive study will illustrate the full potential of the suggested TPMS-based (P and G) scaffolds on the grounds of experimental investigation to study the strength and failure mechanisms at various modes of loading, computational and experimental investigations for permeability analysis, and clinical validation for assessing real scenarios of biocompatibility and tissue responses.

Finally, this work has presented a conceptual patient specific porous implant to treat the large segmental defect cause due to tumor in the femur bone. Conceptualizing basis was dependent on the specific anatomy inclusions and to make it light weight without disparaging mechanical strength. It is believed, using such type of porous implant for large defects would eliminate the size mismatch problem and would accelerate bone regeneration and other biological properties as well as provide sufficient load bearing capability that will be more durable in postoperative period. Overall, the work may be a comprehensive basis of the patient-specific porous implant manufacturing and treatments on demand.

Future Scope of Work

The focus of this thesis was on the development of TPMS unit cells that were specially designed to create a framework for mechanical and fluidic analysis. These scaffolds have shown the potential to mimic bone morphology and biomechanical characteristics. However, these scaffolds have homogeneous morphological features, resulting in little variance of biomechanical and fluidic properties throughout the structure. In reality, the host bone to be replaced has continuous non-homogeneity throughout the internal structure that leads to continuous variation in biomechanical properties. To meet these requirements, functionally graded porous structures in the same framework will be a better alternative for developing patient-specific scaffolds. Additionally, to fulfil the exact bone tissue requirements, morphological, mechanical, as well as fluidic performance on the above-mentioned functionally graded scaffolds must be studied.