In Vitro Biomechanical and Osseo-integrative Properties Evaluation of 3D-Printed Weaire-Phelan Ti-Scaffolds for Bone Repair Applications

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Summary

This study investigates the cytocompatibility and biomechanical viability of Weaire-Phelan (WP) Ti-alloy scaffolds as bone replacement components. Five WP scaffolds with varying porosities were evaluated for their structural robustness, hemodynamic properties and capacity for bony integration.

Introduction

Additively manufactured metallic scaffolds have gained traction in bone tissue engineering. This study aims to evaluate the structural, hemodynamic and cytocompatibility properties of WP Ti-alloy scaffolds.

Methods

Five Weaire-Phelan (WP) scaffolds with varying porosities (50%, 60%, 70%, 80%, 90%) were designed by altering the strut diameter of the unit cell. These scaffolds were fabricated using the direct metal deposition additive manufacturing technique. To assess cytocompatibility, MG63 osteoblast cell lines were used to evaluate human bone cell attachment on the scaffolds. Hemodynamic properties, e.g. maximum flow velocity and wall shear stress (WSS) were assessed using CFD. Mechanical performances, e.g. compressive modulus, yield strength, and fatigue were tested through uniaxial compression tests [1].

Results and Discussion

The designed WP scaffolds were fabricated using additive manufacturing with minimal mass discrepancies (~0.1%). Their mechanical performance, with elastic moduli ranging from 0.2 to 20 GPa, aligns with natural bone tissue properties. Fatigue results show that scaffolds, except WP90, can be finely tuned to match human bone characteristics. WPD50 and WPD60 scaffolds align closely with cortical bone fatigue strength, making them suitable for load-bearing orthopedic applications, while WPD80 and WPD70 align more towards cancellous bone. Fluid flow within the scaffold's porous structure exhibited variable velocities, and WSS values were optimal ($0 < WSS < 60$mPa) for promoting bone cell growth, MSC differentiation, and bone mineralization. A pressure drop pattern similar to trabecular bone was also observed. WP scaffolds with different porosities (90%, 80%, 70%) consistently achieved permeability and relative modulus comparable to trabecular bone. Notably, MG63 cell growth was higher on WP70 scaffolds, indicating enhanced osteogenic activity.

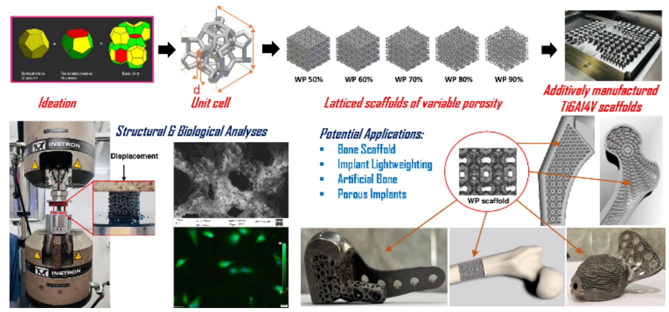

Figure 1: 3D Printed Weaire-Phelan Ti-Alloy Scaffolds of Various Porosities for Bone Replacement Components and Implant Infills

Conclusions

Scaffolds with higher relative density/ lower porosity (WP50, WP60) exhibited superior mechanical properties compared to those with lower relative density/ higher porosity (WP70, WP80, WP90). Scaffolds with higher porosity demonstrated improved permeability and hemodynamic properties, implying better osteogenic potential which was confirmed with MG63 cell line. The effective elastic moduli of WP scaffolds were consistent with natural bone tissue. The fatigue characteristics of WP scaffolds, except WP90, can be finely tuned to match human bone. WPD50 and WPD60 align closely with cortical bone for load-bearing applications, while WPD80 and WPD70 align with cancellous bone. Overall, WP scaffolds show potential for enhanced osseointegration, structural conformity, and customization.

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References

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