An integrated experimental and analytical approach for the analysis of the mechanical interaction between metal porous scaffolds and bone

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Summary

Porous metal structures are extensively used in orthopedic implants to enhance osteointegration and mitigate stress shielding by reducing implant stiffness. Despite numerous numerical studies, experimental data on the effects of porosity and material properties on bone-implant interaction remain limited. This study integrates numerical and experimental methods to investigate the compressive behavior of porous metal scaffolds embedded in bovine cortical bone samples. Bone strain data obtained from Digital Image Correlation (DIC) were compared with finite element analysis (FEA) results. An analytical model of the implant-bone composite was employed to estimate the impact of scaffold stiffness on implant-bone load distribution. The findings indicate that scaffold porosity improves load transfer to the bone, and Ti6Al4V exhibits superior mechanical compatibility compared to CoCrMo.

Introduction

Porous metal structures have become a standard feature of orthopedic implants such as joint endoprostheses. The benefits of the pores are twofold: they enhance the cementless primary stabilization of the implant by increasing osteointegration and reduce the overall stiffness of the implant thus minimizing stress-shielding [1]. However, most studies on stress shielding of orthopedic devices rely solely on FEA [2]. This study aimed to use an integrated analytical and experimental approach to investigate the influence of porosity and material properties on the mechanical interaction in compression between metal porous scaffolds and bovine cortical bone. The results of in-vitro experimental tests were compared to those obtained from FEA and from a spring-based model of the scaffold-bone compound.

Methods

6×6×9 mm porous scaffolds were modelled using 1.5 mm cubic unit cells with 1 mm holes and 1.2 mm spherical cavities and were fabricated via selective laser melting of CoCrMo powder [3]. 18×18×6 mm bone samples, featuring cavities matching the scaffold dimensions, were milled from fresh bovine cortical bone. DIC analysis was used to measure bone strains during axial compression of the scaffold-bone samples up to failure (Figure 1, left).

FEA of the implant-bone compound was performed to estimate the influence of scaffold porosity and material type (Ti6Al4V vs CoCrMo) on bone strain distribution and reaction forces under the same boundary conditions of the experimental setup. A linear elastic spring-based analytical model of the scaffold-bone compound was used to estimate the effect of the material on the bone reaction forces.

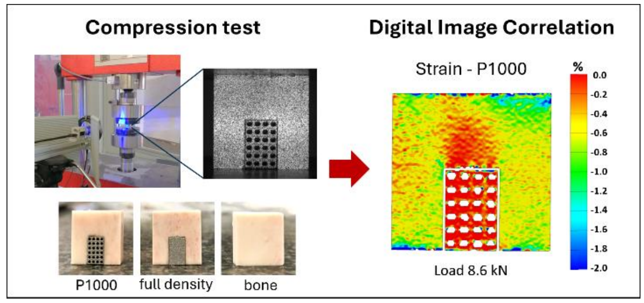

Figure 1: Top left, compressive test on one of the porous scaffold-bone compounds. Bottom left: porous scaffold-bone compound; full-density scaffold-bone compound, and full bone specimen. Right, exemplary DIC strain map of the porous scaffold-bone compound at 8.6 kN compressive load.

Results and Discussion

Based on the experimental analysis, the lateral bone regions adjacent to the porous scaffold experienced a maximum deformation of 7000 $\mu\varepsilon$, which is closely comparable to the 7500 $\mu\varepsilon$ observed in the intact bone sample. According to FEA, Ti6Al4V scaffolds resulted in bone strain and reaction forces closer to those in the full bone, compared to CoCrMo scaffolds. The reaction forces acting on the bone increased respectively by 35% and 89% when using the porous scaffold and the full-density.

Conclusions

The present findings confirm that metal porous scaffolds help promote a more uniform bone strain distribution compared to full density implants. In addition, Ti6Al4V scaffolds appear to be more suitable to transfer stresses to the bone compared to same-size CoCrMo scaffolds. While more evidence should be sought, the outcome of this study may be applied to develop orthopedic devices with optimized osseointegration properties and reduced stress-shielding.

Acknowledgments

Ministero della Salute 5 × 1000.

References

[1] Tan et al. (2017). *Mater Sci Eng C*, **76**: 1328-1343.
[2] Safavi et al. (2023). *J Orthop Surg Res*, **18(1)**: 42.
[3] Caravaggi et al. (2019). *J Biomed Mater Res Part B*; **107B**: 2343–2353.