Computational Evaluation of Biodegradable Bone Tissue Scaffold Designs Using Mechanobiological Modeling

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Summary

Large bone fractures often lead to non-union, with 3D-printed tissue scaffolds emerging as a promising solution. This study presents a novel mechanobiological computational model to investigate the effects of implanted biodegradable scaffold architecture on bone formation. Both scaffold degradation and bone regeneration were simulated showing that larger filament sizes enhance bone formation and increase degradation.

Introduction

Around 40 million severe bone fractures occur globally each year, with 10–15% progressing to non-union [1]. Promising strategies to treat critical-sized bone fractures are 3D-printed tissue scaffolds [2]. Computational methods could play a pivotal role in evaluating the architectural and environmental properties of these scaffolds, including the influence of degradation, to elucidate the relationship between material composition and scaffold design. But currently bone tissue scaffolds are designed through experimental methods rather than simulation due to the difficulty in quantifying mechanobiological relationships. This study aims to investigate the effect of biodegradable bone scaffold architecture on bone formation using an innovative computational approach.

Methods

Figure 1 shows the mechanobiological computer model used.

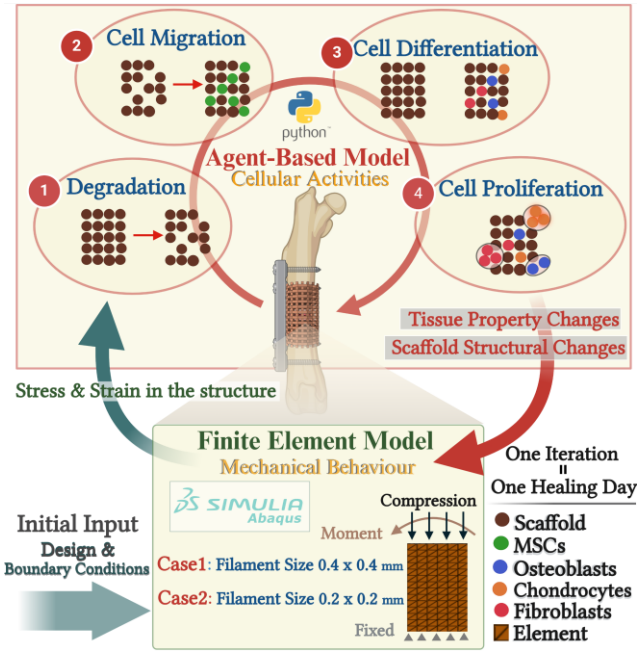

Figure 1: Mechanobiological model coupling a finite element and agent-based model to simulate bone healing over 90 days

The novel model was developed by enhancing our previous work [3]. It used the finite element method to calculate the mechanical stress (Abaqus/CAE 2022, Simulia, Rhode Island, USA) coupled with a novel agent-based model calculating scaffold degradation and bone tissue formation (Python, 2.7) affected by the stress environment and time. Two scaffold designs (filament sizes of 0.4x0.4mm and 0.2x0.2mm) were subjected to lower limb gait load for 90 days.

Results and Discussion

The scaffold with larger filament sizes produced 19 mm^3 greater bone formation and 0.1% higher mass loss than the smaller filament scaffold. Larger filament thicknesses at the distal parts of the fracture, provided better mechanical support for cells, and larger surfaces for cell attachment, see figure 2.

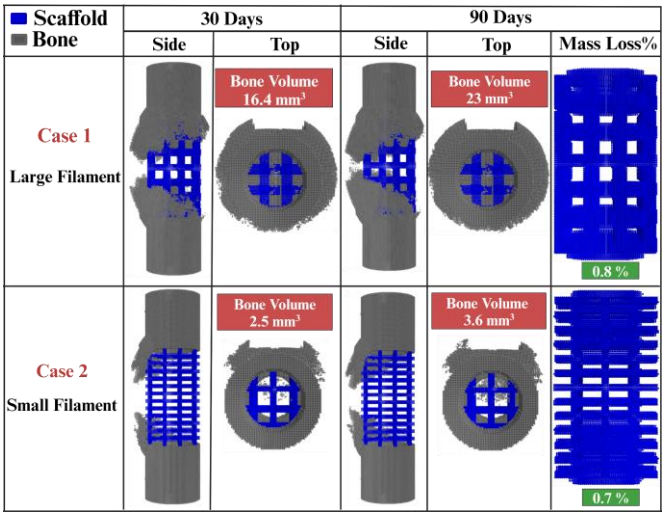

Figure 2: Visualisation of tissue scaffold degradation (blue) and bone formation (grey) for the large and small filament scaffolds after 30 and 90 days.

Conclusions

The model successfully simulated bone scaffold degradation and bone formation dynamically for 90 days. To the author's knowledge this is the first model to explore both these phenomena. Future work will use the model to optimize functional design, which could minimize the use of expensive practical experiments (*in vitro*/*in vivo*) and reduce animal use.

References

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[3] Alshammari, A. et al. (2023). *Polymers* **15(19):** 3918