NUMERICAL INVESTIGATION OF THE EFFECT OF SHAPE MODIFIED STRESS ENVIRONMENT ON OSTEOBLAST BONE REMODELLING.

Adel Alshammari (1,2), Fahad Alabdah (1,2), Weiguang Wang (1), Glen Cooper (1)

1. School of Engineering, University of Manchester, UK; 2. University of Hail, Saudi Arabia.

Introduction

Approximately 40 million bone fracture cases occur annually around the world and 5-15% of these fractures result in non-union or impaired healing [1]. Synthetic bone tissue engineering scaffolds are promising alternative treatments for critical-sized bone fractures [2]. Materials science has provided excellent progress in developing these scaffolds, leading to multiple innovative solutions such as 3D printed polymer-ceramic composite scaffold [3]. However, the function of shape in scaffold design has not been investigated to the same extent. Current tissue scaffolds mainly adapt regular architecture, which may limit their functionality, particularly for the regeneration of large defects. The aim of this study is to investigate the effects of the shape of scaffold fibres in a mechanically stressed environment on cell proliferation, migration, differentiation, and bone formation.

Methods

A numerical model adapted from Perier-Metz *et al.* [4] was used to create a mechano-biological simulation using Abaqus/CAE 6.18 (Simulia, Rhode Island) and C++ (ISO/IEC 14882:2020), . The biological behaviour was modelled on three types of scaffold fibres: a regular 1 mm diameter cylinder, 1 mm diameter truncated cones with draft angles of -3° and -6°. Each fibre was designed as 3mm long and subjected to a constant compressive load of 15 Pa along their axis. 30% of the free positions of the distal ends of the fibre were initially seeded with mesenchymal stem cells, and the simulation was run over 180 iterations, representing a 6-month time-period, to model cell migration, differentiation, and proliferation.

A framework as presented in Figure 1, was used to calculate visual representations of new tissue formation using custom MATLAB code. The results of cell migration and bone volumes are shown in Figures 2A and 2B.

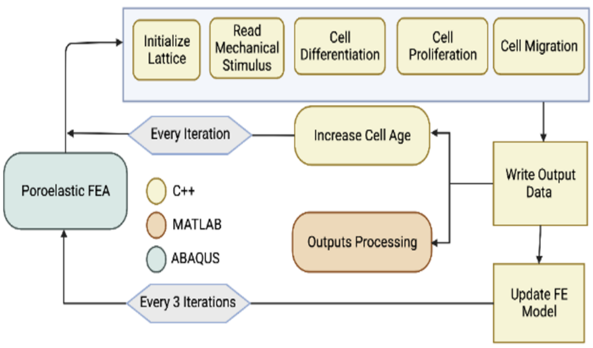

Figure 1: Computer framework of multiscale Mechano-biological model methodology illustration.

Results

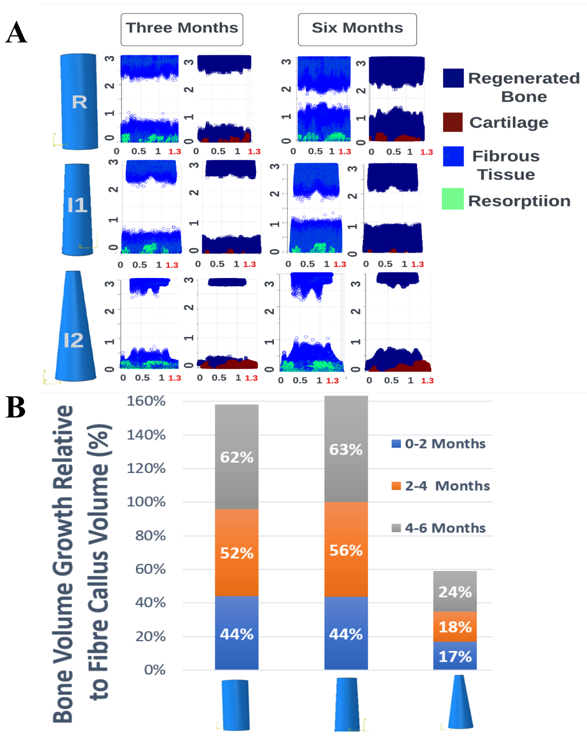

Figure 2: A. Tissue formation (fibrous, cartilage and bone) at three and six month periods for the three fibre shapes. Axis in mm along length and width of fibre/callus. B. Percentage bone volume growth at two, four and six months normalised to fibre callus volume. R is a regular fibre shape, I1 is an irregular fibre shape with -3° draft angle, and I2 is an irregular fibre shape with -6° draft angle.

Discussion

The results from this study show that scaffold fibre shape has a significant impact on bone regeneration under mechanically stressed environments, as represented by over 100% volume change due to the shape change in terms of bone formation. Developed from a previous validated study [4], this mechano-biological relationship model has successfully predicted the bone regeneration, and future work will focus on extending this research to a full scale 3D printed bone tissue engineering scaffold, and validate the results in in vitro and in vivo environments.

References

1 Osteo-Pharma BV, www.osteo-pharma.com Acc. Jan 2023.
2 Reznikov, N et al. *Biomaterials, 194*: 183–194, 2019.
3 Wagoner Johnson. Acta Biomater, 7: 16-30, 2011.
4 Perier-Metz, *et al. Front. Bioeng. Biotechnol. 8:585799,* 2020.