POROUS TITANIUM/BRUSHITE SCAFFOLDS FOR THE TREATMENT OF LARGE BONE DEFECTS

Dina Abdulaziz (1), Antonios Anastasiou (2), Vasiliki Panagiotopoulou (3), El Mostafa Raif (4), Peter Giannoudis (5), Animesh Jha (1)

1. School of Chemical and Process Engineering, University of Leeds, UK; *2. Department of Chemical Engineering and Analytical Science, University of Manchester, UK*; *3. School of Mechanical Engineering, University of Patras, Greece*; *4. Division of Oral Biology, University of Leeds, UK*; *5. Academic Department of Trauma and Orthopaedic, School of Medicine, University of Leeds, UK*

Introduction

The repair of large bone defects is one of the most critical clinical challenges in trauma surgery. Even though different types of materials and designs have been developed, most of these trials presented various deficiencies after the translation in the clinic. None of the proposed designs and materials could accurately mimic the mechanical and biological behaviour of natural bone. The "ideal" bone scaffold for treating large fractures must have collective properties to support healthy bone growth and avoid malunion or non-union [1]. This work aims to develop a porous composite scaffold that can imitate the natural bone by taking favourable characteristics of different materials to produce a bone scaffold that is biocompatible, appropriate for load-bearing applications, stimulates bone growth and promotes vascularisation at the defect site.

Methods

Porous titanium/brushite scaffolds (Ti/DCPD-Fe) were fabricated using powder metallurgy with a space holder process. Ti powder was mixed in different ratios with 10% iron-dopped brushite. In order to create the porous structure, potassium chloride powder (0, 20, 40 vol%) was added as a space holder. Three temperatures were used for sintering in an inert atmosphere (800, 950, 1100 ˚C) with a sintering time constant of 2 h. The synthesised scaffolds were characterised in terms of phase constitution and porosity using XRD, helium pycnometer, SEM and micro-CT techniques. Based on the design of experiments principles (DOE), a parametric study was conducted to identify the appropriate fabrication conditions (mineral content, porosity and sintering temperature) that result in mechanical properties similar to those of natural cortical bone. Using ANSYS WORKBENCH, finite element analysis was done to investigate the stress and strain behaviour of the synthesised scaffolds. The CAD used was for femur bone with a 5 cm gap fulfilled with the synthesised scaffold (Figure 1a). *In vitro* cytotoxicity and proliferation assays were followed as well.

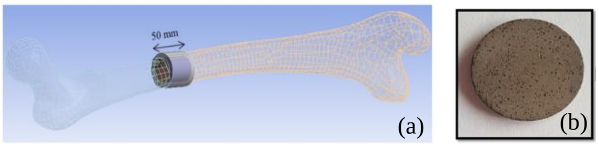

Figure 1: The CAD of femur bone with a large bone defect (50 mm) replaced with the synthesised scaffold (a), the fabricated porous (Ti/DCPD-Fe) scaffold (b).

Results & Discussion

XRD results confirmed that no oxidation of Ti was observed, even at high temperatures, while the heated iron-doped brushite was transformed into β-pyrophosphate known for its osteoconductive properties and controllable degradation rate. The powder metallurgy with space holder process was feasible in fabricating scaffolds with open, large enough and interconnected pores, which are supposed to allow vascularisation and ease penetration of cells. The synthesised scaffolds had open porosity ranging between 26 – 60% with a pore size was ~ 100 – 850 µm and interconnectivity of up to ~ 95%. The elastic modulus values for the porous composite scaffolds ranged between 3.30 – 20.50 GPa based on porosity value, mineral ratio and sintering temperature. Young's modulus values for the porous composite scaffolds are comparable with that of the human femur bone (4 - 20 GPa) [2], which indicates they are supposed to minimise the stress-shielding effect. Also, they exhibited suitable compressive strength ~ 130 - 165 MPa at sintering temperature 1000ºC or higher. These values are similar to the femoral cortical bone ~ 90 - 180 Mpa [2]. The numerical results showed that scaffolds with higher porosity and mineral content had lower stiffness values closer to that of natural bone and exhibited flexible biomechanical behaviour at the interface bone/scaffold. These findings suggest that the synthesised scaffolds have the potential to perform well for bone regeneration within large defects and could be biomechanically flexible in interaction with the surrounding tissue. *In vitro* outcomes displayed that all the synthesised scaffolds were non-toxic and biocompatible. Furthermore, cells presented excellent adhesion and growth, and their morphology showed a healthy attachment with a well-spread shape, which is indicative of high cellular interaction with all scaffolds' surfaces.

References

1. Andrzejowski, P. and Giannoudis, P.V., The 'diamond concept' for long bone non-union management, Journal of Orthopaedics and Traumatology, 20(1): p. 1-13, 2019.
2. Öhman, C., et al., Compressive behaviour of child and adult cortical bone, Bone, 49(4): p. 769-776, 2011.

Acknowledgements

This work was supported by Industrial Fellowship from the Royal Commission for the Exhibition of 1851.