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FABRICATION OF TITANIUM LATTICE STRUCTURES BY SELECTIVE LASER MELTING FOR OSTEOCHONDRAL TISSUE REGENERATION

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ABSTRACT: Reconstruction of damaged osteochondral tissue at skeletal joints has remained a significant challenge due to their complex structure and multiple tissue segments including articular cartilage, subchondral bone and interfacial tissues. The aim of this study is to design, optimize and characterize an osteochondral scaffold produced via combination of collagen hydrogel and titanium scaffold fabricated using selective laser melting. The development of titanium lattice scaffolds with distinct cartilage and bone phases which has the potential to match the structural and mechanical requirements of osteochondral tissue regeneration are reported.

KEYWORDS: Additive Manufacturing, 3d Printing, Selective Laser Melting, Osteochondral Tissue Regeneration

INTRODUCTION
Osteochondral defects can be caused by either trauma related injuries or natural degradation. As estimated in 2008, over 59 million people in American and European Union suffer from osteoarthritis which may leads to osteochondral defects (Csaki et al., 2008). Osteochondral tissue regeneration remains clinical challenging due to its multilayered structure comprised of multiple tissue segments involving cartilage, bone and the cartilage-bone interface (Panseri et al., 2012, Kon et al., 2014).

In the last decade, several tissue engineering approaches have been developed to address the clinical challenge. The aim of tissue engineering is regenerating functioning tissue by combining three key factors: scaffold, functioning cells and bioactive molecules such as growth factors (Hollister, 2005, Wang et al., 2012, Wang et al., 2015). As scaffolds play a critical role in osteochondral regeneration, such scaffolds should have a rigid osseous structure to provide mechanical strength and a porous phase to allow seeding, migrating and extracellular matrix (ECM) remodeling of cells (Duan et al., 2013, Nover et al., 2015).

As one of the essential component of ECM, Type I collagen has been widely used as tissue scaffold material. It is biocompatible and provides favorable cellular micro-environment to induce chondrogenesis of mesenchymal stem cells (MSCs) in vivo. For example, collagen-glycosaminoglycan phosphate biphasic scaffold were evaluated in caprine femoral condyle and lateral trochlear sulcus osteochondral defects model. After 26 weeks of implantation, both scaffolds provide indications of structural repair (Getgood et al., 2012). Titanium has been widely used in transplantable devices due to advantages such as superior mechanical properties, biocompatibility and corrosion resistance (Sing et al., 2015). In addition, the development of additive manufacturing or 3D printing techniques provides exciting opportunities to fabricate new transplantable scaffolds with complex geometry (Chua et al., 2005, Yeong et al., 2005, Lee and Yeong, 2014, Ng et al., 2014, Yeong and Chua, 2014, Wang et al., 2015, Lee et al., 2016).
Among those techniques, selective laser melting (SLM) is particularly useful for fabricating metallic porous structures. SLM is a form of powder bed fusion additive manufacturing. It uses a laser power source to fuse powder materials to form functionally parts directly based on computer aided design (CAD) files (Sing et al., 2016, Sing et al., 2016).

In this paper, metallic porous structures using commercially pure titanium were produced using SLM and combined with type I collagen to match the structural and mechanical requirements of osteochondral tissue regeneration.

**MATERIALS AND METHODS**

Titanium Scaffold Design and Fabrication using Selective Laser Melting
The titanium scaffolds are designed using cubic unit cells of 1 mm x 1 mm x 1 mm. The total structure volume is 10 mm x 10 mm x 2 mm. The SLM machine (SLM Solutions Group AG, Germany) is equipped with a Gaussian beam fiber laser with maximum power of 400 W and a focal diameter of 80 μm. All processing occurred in an argon environment with less than 0.05 % oxygen to prevent oxidation and degradation of the material during the process.

Infiltration of Collagen Hydrogel
2 mg/ml collagen hydrogels were prepared according to the manufacturer’s instruction. Briefly, the required volume of collagen was neutralized with 1 M NaOH in PBS. The neutralized collagen solution was added to the metal scaffolds with a holding mould and allowed to gel at 37 °C for 30 min.

Scanning Electron Microscopy
Scaffolds were frozen at -20 °C for two days and lyophilized. All samples were gold-sputtered at 18 mA for 10 sec. Images were taken with a scanning electron microscope (JEOL, USA) at an accelerating voltage of 10kV under high vacuum.

**RESULTS AND DISCUSSION**
As shown in Figure 1, the design concept of the scaffolds involved a porous titanium scaffold base to mimic osseous structure mechanical strength and a type I collagen phase as the cartilage phase.

![Cartilage phase
(Collagen hydrogel)](3D printed metal scaffold)

Figure 1. Design concept of the scaffold.
Titanium-collagen scaffolds were prepared by immersing the titanium scaffold in de-gassed collagen solution while shaking gently. Excess collagen solution was removed before gelling at 37 °C. As shown in Figure 2, all designed square pores are visible. The interconnected pores allowed infiltration of collagen through the titanium scaffolds.

Figure 2. Photographs take from top (left) and side (right) of cylindrical porous titanium scaffold with infiltrated type I collagen.

Figure 3 shows the SEM photographs of freeze-dried titanium-collagen scaffolds. The surface of titanium scaffolds was rough due to the SLM powder fusion process. The top collagen layer was between 200 μm and 500 μm. Infiltration of collagen into the titanium scaffold was also evidenced.

Figure 3. SEM photographs of titanium-collagen scaffold at 50X (left) and 170X (right) magnifications.
CONCLUSION

Titanium-collagen scaffolds provide bone-like mechanical properties while having the potential to support cartilage growth. The SLM technique offers control over the micro-scale complex design of the titanium base. Future studies will aim to optimize the designs and evaluation with in vitro cell culture experiment will be carried out. It is anticipated that scaffolds can be tailored to better suit the biochemical and mechanical requirements for osteochondral tissue regeneration.

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REFERENCES


