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Repairing a critical-sized bone defect with highly porous modified and unmodified baghdadite scaffolds

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ABSTRACT

This is the first reported study to prepare highly porous baghdadite ($Ca_3ZrSi_2O_9$) scaffolds with and without surface modification and investigate their ability to repair critical-sized bone defects in a rabbit radius under normal load. The modification was carried out to improve the mechanical properties of the baghdadite scaffolds (particularly to address their brittleness) by coating their surfaces with a thin layer (~400 nm) of polycaprolactone (PCL)/bioactive glass nanoparticles (nBGs). The β-tricalcium phosphate/hydroxyapatite (TCP/HA) scaffolds with and without modification were used as the control groups. All of the tested scaffolds had an open and interconnected porous structure with a porosity of ~85% and average pore size of 500 μm. The scaffolds (six per scaffold type and size of 4 mm × 4 mm × 15 mm) were implanted (press-fit) into the rabbit radial segmental defects for 12 weeks. Micro-computed tomography and histological evaluations were used to determine bone ingrowth, bone quality, and implant integration after 12 weeks of healing. Extensive new bone formation with complete bridging of the radial defect was evident with the baghdadite scaffolds (modified/unmodified) at the periphery and in close proximity to the ceramics within the pores, in contrast to TCP/HA scaffolds (modified/unmodified), where bone tended to grow between the ulna adjacent to the implant edge. Although the modification of the baghdadite scaffolds significantly improved their mechanical properties, it did not show any significant effect on in vivo bone formation. Our findings suggest that baghdadite scaffolds with and without modification can serve as a potential material to repair critical sized bone defects.

1. Introduction

Repair and regeneration of critical size bone defects are challenging, and are hampered by frequent suboptimal outcomes, resulting in a significant increase in morbidity at a high economical cost to society [1]. The gold standard for bone defect repair – bone grafting with autologous bone – has significant drawbacks such as limited availability, second site surgery and donor site morbidity, leading to prolonged hospitalization [2]. Allografting also has several disadvantages which limit its use, including reduced bioactivity and increased risk of disease transmission. Scaffold-based solutions offer an alternative way for promoting the bone growth in large bone defects by using a porous material [2–4]. Significant efforts have been made to develop an ideal synthetic scaffold that reproduces bone's structural properties combined with the necessary porosity, interconnectivity, bioactivity and mechanical strength [5,6]. While bioactive ceramics such as TCP (beta-tricalcium phosphate), HA (hydroxyapatite), TCP/HA (β-tricalcium phosphate/hydroxyapatite) and bioactive glasses bond with hard (and in some cases soft) tissues, they are brittle and are difficult to form into complex shapes in highly porous form (porosity >80%, pore size >300 μm and interconnectivity between pores ~100) while providing an adequate mechanical stability for the defect site [7–13].

Calcium silicate ceramics have been proposed as potential biomaterials for bone tissue regeneration due to their good bioactivity and improved mechanical properties. However, a major drawback of the calcium silicate ($CaSiO_3$) bioceramics is their chemical instability. Our strategy for developing new biomaterials for use as bone substitutes is to select $CaSiO_3$ as the base material and to modify it through the incorporation of elements in order to enhance its physical and biological properties. Based on our previous investigations we identified zirconium as a candidate for inclusion with calcium silicate due to its ability to enhance bioactivity of calcium phosphate based materials [14]. We generated a calcium silicate ceramic containing zirconium and determined the optimal phase composition to be chemically identical to the previously identified mineral "baghdadite" [15] (Provisional Patent Application # 2007905843) and demonstrated its in vitro biocompatibility with

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