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Bulk properties and bioactivity assessment of porous polymethylmethacrylate cement loaded with calcium phosphates under simulated physiological conditions

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ABSTRACT

Polymethylmethacrylate (PMMA) cements are widely used in spinal surgery. Nevertheless, these types of cements present some documented drawbacks. Therefore, efforts have been made to improve the properties and biological performance of solid PMMA. A porous structure would seem to be advantageous for anchoring purposes. This work studied the bulk physicochemical, mechanical and interconnectivity properties of porous PMMA cements loaded with various amounts of calcium phosphate (CaP). As a measure of bioactivity, changes of PMMA cements under simulated physiological conditions were studied in a calcium phosphate solution for 0, 3, 7, 14, 21 and 28 days. Scanning electron microscopy (SEM), X-ray diffraction (XRD), Fourier transform infrared spectroscopy (FTIR), micro-computed tomography (μ-CT) and mechanical compression tests were performed to characterize the morphology, crystallographic and chemical composition, interconnectivity and mechanical properties, respectively. SEM allowed observing the result of loading CaP into the porous PMMA, which was corroborated by XRD, FTIR and μ-CT. No interference of the CaP with the PMMA was detected. μ-CT described similar interconnectivity and pore distribution for all CaP percentages. Mechanical properties were not significantly altered by the CaP percentages or the immersion time. Hence, porous PMMA was effectively loaded with CaP, which provided the material with properties for potential osteoconductivity.

1. Introduction

Polymethylmethacrylate (PMMA) is a non-adhesive acrylic polymer that is widely used in orthopedics as a bone cement for implants and as a vertebral filling material for spinal surgery, i.e. vertebroplasty and kyphoplasty [1,2]. The orthopedic use of PMMA cement was introduced in the early 1960s by Charnley and this was the first cement used for spine applications [3]. PMMA has been widely investigated as a bone cement for over 40 years and many injectable PMMA cement formulations designed for vertebral body applications are commercially available [4,5]. Tracking the material during vertebral filling is important to avoid leakage of the material, which increases the risk of injuries or adverse effects [6–8]. Therefore, PMMA cements can possess radiopaque properties when loaded with zirconia, barium sulfate, iodine, tantalum or tungsten [9,10]. Reported drawbacks with PMMA are poor integration with bone, high exothermic polymerization reaction and monomer toxicity [11–14]. Although Braunstein *et al.* [15] recently reported one rare case were a significant callus was formed around solid PMMA after an implantation period of 3.5 years in a patient, this publication also indicates that additional factors such as biphosphonates intake, the possibility of bone stimulation due to a microfracture environment and space between bone and PMMA need to be considered. As a result, PMMA *per se* does not present ideal mechanical and biological characteristics for long *in vivo* performance and the bone–PMMA interface may be the weak link causing the occurrence of adjacent level fractures after spinal augmentation, where the main mechanical mode of loading/deformation is compression [16,17]. The human cortical bone presents compressive and elastic modulus values of ~130–180 MPa and 12 GPa, respectively, while the cancellous bone presents values of ~4–12 MPa with an elastic modulus of ~81 MPa [18,19]. Lower mechanical values for PMMA cements are suitable to avoid this type of fracture.

Studies over the last decades with PMMA indicate that better materials for spinal bone filling applications must be found [1,5]. Hence, continuous attempts for modifying the characteristics of PMMA to enhance its properties have been made. Calcium phosphate (CaP) materials can be resorbed and transformed into new bone, have a bioactive and osteoconductive capacity and are

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