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Silicon-stabilized α-tricalcium phosphate and its use in a calcium phosphate cement: Characterization and cell response

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ABSTRACT

α-Tricalcium phosphate (α-TCP) is widely used as a reactant in calcium phosphate cements. This work aims at doping α-TCP with silicon with a twofold objective. On the one hand, to study the effect of Si addition on the stability and reactivity of this polymorph. On the other, to develop Si-doped cements and to evaluate the effect of Si on their in vitro cell response. For this purpose a calcium-deficient hydroxyapatite was sintered at 1250 °C with different amounts of silicon oxide. The high temperature polymorph α-TCP was stabilized by the presence of silicon, which inhibited reversion of the β → α transformation, whereas in the Si-free sample α-TCP completely reverted to the β-polymorph. However, the β–α transformation temperature was not affected by the presence of Si. Si–α-TCP and its Si-free counterpart were used as reactants for a calcium phosphate cement. While Si–α-TCP showed faster hydrolysis to calcium-deficient hydroxyapatite, upon complete reaction the crystalline phases, morphology and mechanical properties of both cements were similar. An in vitro cell culture study, in which osteoblast-like cells were exposed to the ions released by both materials, showed a delay in cell proliferation in both cases and stimulation of cell differentiation, more marked for the Si-containing cement. These results can be attributed to strong modification of the ionic concentrations in the culture medium by both materials. Ca-depletion from the medium was observed for both cements, whereas continuous Si release was detected for the Si-containing cement.

1. Introduction

Calcium phosphate cements (CPC) have been successfully used as synthetic bone grafts for the last three decades due to their excellent biocompatibility, bioactivity and osteoconductivity [1]. However, nowadays there are still many efforts focused on improving their biological performance. Several strategies have been proposed, namely the development of porous cements to enhance material resorption, tissue colonization and angiogenesis [2], the addition of drugs and growth factors [3], and the incorporation of some specific ions which play relevant roles in bone metabolism [4,5], with the aim of using the cements as a kind of "ion eluting" material.

One of the most common reactants for CPC is α-tricalcium phosphate (α-$Ca_3(PO_4)_2$, α-TCP). Upon contact with water α-TCP hydrolyses to a calcium-deficient hydroxyapatite (HA) [6]. α-TCP is one of the three polymorphs of TCP, which is stable above ~1125 °C [7]. Even though the low temperature β-polymorph is widely used as a ceramic for orthopedic applications for its well-known biocompatibility, α-TCP is a much more efficient reactant for CPC due to its lower density and higher free energy of formation, being more reactive and soluble than β-TCP. It is known that the relative stability of the α- and β-polymorphs is highly affected by the presence of some impurities [8]. Thus whereas Mg is known as an element that stabilizes the β-phase [9,10], Si is known to stabilize the α-form [11–13].

The interest of doping α-TCP with silicon is twofold. On the one hand, it can stabilize this phase at low temperature, facilitating the fabrication process, which requires high temperature thermal treatments and in many cases fast cooling or quenching to avoid reversion of the reconstructive β → α transformation. On the other hand, silicon is expected to enhance the bioactivity [13,14] and the osteogenic potential of the material [13,15,16]. Indeed, silicon is a bone trace element with a specific metabolic role connected to bone growth, specifically during the initial formation stages [17]. There are several studies showing biological improvements associated with silicon, although the mechanism by which silicon improves the bioactivity and the cellular response of a material

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