Toughening of bio-ceramics scaffolds by polymer coating

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Abstract

In this work, polycaprolactone-coated alumina scaffolds were produced and characterized to validate the concept of polymer–ceramic composites with increased fracture resistance. Alumina scaffolds were sintered using a foam replication technique. An open-porous structure was achieved with ∼70% porosity and 150 μm mean pore size. The polymer coating was obtained by infiltrating the scaffold with either a polycaprolactone solution or a polycaprolactone nanodispersion. The latter was obtained by an emulsion–diffusion technique. Dynamical Young modulus measurements and four-point bending tests were conducted to evaluate the mechanical properties of the composites. It was found that their elastic behaviour is controlled on the first order by the ceramic scaffold, while the fracture energy mainly depends on the polymer phase. A 10–20 vol.% addition of polycaprolactone to alumina scaffolds led to a 7- to 13-fold increase of the apparent fracture energy. SEM observations showed that toughening is due to crack bridging by polymer fibrils.

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1. Introduction

Highly porous scaffolds with open structure are today the best candidates for cancellous bone substitution.1 As compared to auto-grafts, synthetic bone substitutes involve less invasive surgery (a two step operation is necessary for the former) and are available in large quantities. As compared to xeno-grafts, the risk of rejection is much less important and the transmission of diseases is avoided.2 Current synthetic scaffolds are processed from ceramic or polymer, but a better combination of mechanical and biological properties may be achieved with a composite or hybrid structure.

Many polymers have been proposed for medical applications,3 either natural (collagen, alginate, glycosaminoglycan, starch, chitin and chitosan) or synthetic (poly(lactic acid), poly(glycolic acid), poly(hydroxybutyrate), poly(e-caprolactone) (PCL), poly(ethylene oxide), poly(p-dioxanone), poly(methyl methacrylate), etc.).4 Each of them presents different biological and mechanical properties, allowing a choice of the right polymer for the right application. However, polymers usually present low modulus (below a few GPa) and creep resistance compared to bones (whose Young modulus ranges between 0.5 and 20 GPa depending on their type). This is the major reason that limits their clinical use for bone substitution.

Calcium phosphate ceramics (i.e. hydroxyapatite (HAP) and tricalcium phosphate (TCP)) and bioactive glasses (silica glasses containing calcium and phosphorus) have proven good biological properties and clinical successes in some specific applications (i.e. tibial osteotomy). However, calcium phosphates and bioactive glasses are brittle, impairing their use for load-bearing applications and making difficult the handling by the surgeon.

Using composites is a method to take advantage of both polymer and ceramics qualities, ideally to achieve materials with high stiffness and high toughness. Such composites can be based either on a polymer or a ceramic matrix and should be highly porous to meet the biological requirements for cancellous bone substitution.

The polymer matrix approach is the most widely studied, with a high number of systems proposed during the last