Improvement of Interfacial Compatibility in Polyurethane/Tricalcium Phosphate Composite Bone Cements Through Filler Surface Modification

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Statement of Purpose: Ceramic biomaterials, such as tricalcium phosphate (TCP), offer biocompatibility and osteoconductivity [1], but have brittle mechanical properties. While 10-μm TCP particles incorporated in an injectable polyurethane matrix (10-20wt%) facilitated cortex development in iliac crest defects in sheep, the TCP did not increase mechanical strength [2]. Interfacial binding between the filler and polymer phases is known to enhance mechanical properties. To improve the mechanical properties of poly(L,DL-lactide)/TCP composites, L-lactide was grafted to TCP prior to blending, but grafting did not achieve improved mechanical properties compared to unmodified TCP composites [3]. In this study, two TCP surface modification methods were compared, wherein PEG and PCL were grafted onto TCP so that they would react with the isocyanate groups in the reactive polyurethane. We hypothesized that a composite material with covalent bonding between the filler and matrix, as well as high (>20 wt%) filler content, would show increased mechanical properties while preserving the osteoconductive biological properties.

Methods: Mineralized bone (MBP) was donated by Osteotech Inc., and was defatted (DFMBP) and demineralized (SDMBP) according to published techniques [4]. β-TriCalcium Phosphate (TCP, grain size distribution 100-300 μm) was purchased from Berkeley Advanced Biomaterials. Polyethylene glycol (PEG, 8000 MW, Alfa Aesar) was adsorbed on the surface of TCP by incubating a 5% suspension of TCP in PEG for 5h followed by filtering and drying under vacuum at 80ºC [5]. PCL was covalently grafted to β-TCP particles by stirring with 5% aqueous phosphoric acid for 1h, followed by washing and vacuum-drying; the resulting protonated material was then reacted with ε-caprolactone at 150°C for 4 days [3]. The molar ratio of β-TCP to ε-caprolactone was 1:10. The product (TCP-PCL) was washed with chloroform, filtered, and dried under vacuum at 40°C for 15 h. Surface compositions were assessed by XPS (PHI 5000 VersaProbe with a 25W monochromatic Al K-α X-ray). Particle size distribution was measured using a Saturn DigiSizer 5200 V1.12 (Micromeritics, Norcross, GA). A poly(ε-caprolactone-co-DL-lactide-co-glycolide) triol (300 g/mol) and lysine triisocyanate prepolymer were used [4,6] to prepare the composites. The triol was mixed with an amine catalyst (TEGOAMIN 33, Goldschmidt) for 1 min, followed by mixing with filler particles for 3 min. Finally, the prepolymer was added to the mixture and mixed for 3 min. The resulting reactive paste was cast into 6 mm cylindrical molds and a load of 0.95 kg was applied until setting was achieved. The green composite was cured at 37°C for 15 h. Compressive mechanical properties were evaluated on wet samples with approximate height of 12 mm using an MTS 858 Bionix Servohydraulic Test System.

Results: The increase in carbon and decrease in calcium content at the surface of TCP (measured by XPS) confirmed the attachment of PEG and PCL to the ceramic surface (Fig. 1). The particle size distribution analysis revealed a decrease in particle size after the surface modification treatments.

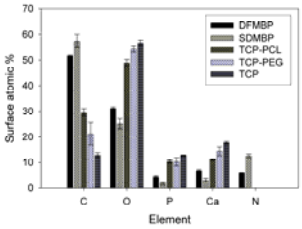

Figure 1. XPS characterization of filler surfaces

Composite materials that contained TCP-PCL as the filler showed comparable mechanical properties to the bone composites and higher than those containing TCP and TCP-PEG. This improvement was verified to be caused by the covalent grafting of PCL to the TCP surface and not by the decrease in particle size (Fig. 2). The TCP-PCL treatment had significantly ($p<0.05$) higher modulus than the TCP and stirred TCP (similar particle size to TCP-PCL) composites (Fig. 2a). While surface treatments did not significantly increase the strength for 45.8 vol% composites, both TCP-PEG and TCP-PCL exhibited significantly higher strengths than TCP or stirred TCP at 56.7 vol% TCP. All materials supported the attachment and proliferation of viable MC3T3 cells *in vitro*.

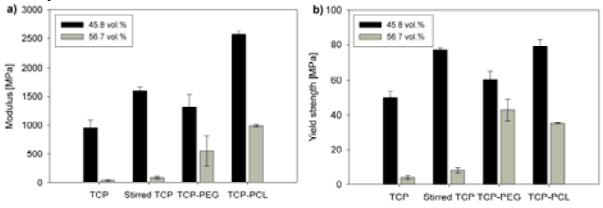

Figure 2. Compressive modulus (left) and strength (right) of TCP composites at low and high filler contents.

Conclusions: By covalently grafting PCL to the surface of TCP, its reactivity with isocyanates was enhanced, resulting in improved interfacial bonding and mechanical properties, especially at high TCP content. This strategy could be useful for fabricating high-strength composites at filler concentrations approaching the random close-packing limit, where accelerated remodeling has been reported due to the percolated, continuous filler phase [4].

References: [1] Tortelli F. Eu Cells and Mat. 2009; 17:1-14 [2] Adhikari R. Biom. 2008;29:3762-3770 [3] Kunze F. Biom. 2003;24: 967-974 [4]Dumas JE. Act Bio. Submitted [5] Vazquez B. Biom. 2005;26:4309-4316 [6] Guelcher SA. Biom. 2008; 29(12):1762-1775. *Supported by the AFIRM (W81XWH-08-2-0034) and the NSF through a CAREER award to SAG (DMR0847711).*