Hydroxyapatite Whisker Reinforced Polyaryletherketone for Orthopaedic and Spinal Implants

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Introduction: Hydroxyapatite (HA) whisker reinforced polymer biocomposites offer a robust system to engineer implant biomaterials with tailored mechanical, biological and surgical function.[1] For example, interbody spinal fusion utilizes an implant inserted in the disc space to restore vertebral height, promote fusion between adjacent vertebrae and stabilize the spine. The high x-ray attenuation of titanium makes radiographic assessment of fusion difficult which has given rise to the use of radiolucent polyaryletherketone (PAEK).[2,3] However, both titanium and PAEK are bioinert which limits their incorporation with the fusion mass and implant stability, and requires augmentation with autograft or BMP. Moreover, neither titanium nor PAEK mimic the mechanical properties of the peri-implant tissue (trabecular bone) which may lead to subsidence, insufficient mechanical stimulation for new bone formation or implant failure. Therefore, the objective of this work was to prepare HA whisker reinforced PAEK to mimic the mechanical properties of trabecular bone while providing HA surface sites for protein/cell adsorption and bony apposition.

Methods: HA whisker reinforced PAEK was first tailored to mimic the mechanical properties of the extracellular matrix of bone,[4] prior to the introduction of porosity. HA whiskers were prepared using the chelate decomposition method.[5] Commercially available PEEK (Victrex 150XF) or PEKK (OXPEKK-C) powders were used as-received. High levels of porosity (up to 90%) and HA whisker reinforcement (up to 50 vol%) were attained using a powder processing approach to mix the HA whiskers, PAEK powder and a NaCl porogen, followed by compression molding at 350-375°C and particle leaching to remove the porogen. The mechanical properties of dense composites and porous scaffolds were measured in uniaxial tension and compression, respectively. Scaffold architecture was characterized using micro-computed tomography (Scanco micro-CT 80). Biocomposite microstructure was characterized using scanning electron microscopy (SEM) and quantitative texture analysis with x-ray diffraction (XRD).

Results: The mechanical properties of dense composites (Table 1) and porous scaffolds (Table 2) were tailored to reasonably mimic those of cortical and trabecular bone, respectively. The scaffold architecture and biocomposite microstructure exhibited characteristics known to be favorable for osteointegration. Scaffold porosity was interconnected with a mean pore size in the range 250-300 μm, as measured by micro-CT (Fig. 1). HA whiskers were well-dispersed within the polymer, predominately aligned along the length of dense composites or plane of scaffold struts, and exposed on surfaces, contributing a micro-scale surface topography.

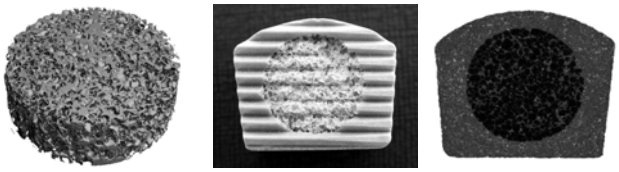
Table 1. Mechanical properties in the longitudinal axis of dense HA whisker reinforced PEEK compared to human cortical bone (≈40-50 vol% apatite).[4] Mean (±SD) values are reported for the elastic modulus (E), ultimate tensile strength (UTS) and strain to failure (ε_f).

HA Content (%)	E (GPa)	UTS (MPa)	ε_f (%)
0	4.6 (0.2)	99.2 (4.6)	2.6 (0.3)
20	10.3 (1.6)	75.0 (5.4)	0.8 (0.2)
40	17.2 (0.7)	56.3 (8.0)	0.4 (0.2)
cortical bone[6]	16-23	80-150	≈3

Table 2. Mechanical properties of 75% porous HA whisker reinforced PEKK scaffolds compared to human vertebral trabecular bone (≈40-50 vol% apatite; 75-95% porosity). Mean (±SD) values are reported for the apparent compressive modulus (E), yield strength (YS) and yield strain (ε_y).

HA Content (%)	E (MPa)	YS (MPa)	ε_y (%)
0	98.2 (10.7)	2.22 (0.25)	2.5 (0.2)
20	149.1 (39.2)	2.24 (0.42)	1.9 (0.3)
40	126.9 (30.1)	1.65 (0.34)	1.6 (0.3)
trabecular bone[7]	20-500	1-3	0.7-1.2

Figure 1. Example implants (left to right): micro-CT reconstruction of a porous (75%) scaffold (10 mm dia.), and a cervical interbody spinal fusion cage (10 mm width) with a dense outer shell and porous (75%) inner scaffold shown by a photograph and cross-sectional image from micro-CT. The biomaterial in each implant is PEKK reinforced with 20 vol% HA whiskers.



Conclusions: HA whisker reinforced PAEK composites were able to be tailored to mimic key aspects of the structure and mechanical behavior of either cortical or trabecular bone by tailoring the level of porosity, as well as the HA whisker content and orientation. HA whisker reinforced PAEK bone ingrowth scaffolds may be advantageous for orthopaedic implant fixation, including interbody spinal fusion (Fig. 1), warranting future animal studies.

References: [1]RK Roeder *et al*., *JOM*, 60:38-45, 2008; [2]M Toth *et al*., *Biomaterials*, 27:324-334, 2006; [3]SM Kurtz *et al*., *Biomaterials* 28:4845-4869, 2007; [4]GL Converse *et al*., *Biomaterials*, 28:927-935, 2007; [5]RK Roeder *et al*., *J. Am. Ceram. Soc*., 89:2096-2104, 2006; [6]DT Riley *et al*., *J. Biomechanics*, 8:393-405, 1975; [7]TM Keaveny *et al*., *Annu. Rev. Biomed. Eng.*, 3:307-333, 2001.