MECHANICAL QUALIFICATION OF A SYNTHETIC, RESORBABLE BONE REPAIR SCAFFOLD

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INTRODUCTION

A synthetic bone repair material may be able to extend or even replace autogenous, cancellous bone graft. Scaffolds based on a porous composite of poly(propylene glycol-co-fumaric acid) and hydroxyapatite were evaluated for potential application to bone repair. Temporal compressive and morphological properties of the bone repair material were assessed following degradation under simulated physiological conditions. Scaffold porosity was desired for osteointegration and average pore sizes were on the order of 200 µm. Initial compressive strength of the repair material was comparable to cancellous bone and decreased by approximately 50 percent and 85 percent following degradation for 3 and 6 weeks, respectively. The test material created a dynamic system capable of initially providing mechanical integrity to bony voids and a degradation mechanism for promoting the ingrowth of native bone.

MATERIALS AND METHODS

Preparation of Bone Repair Material

The poly(propylene glycol-co-fumaric acid) (PPF)-based bone repair material consisted of a two-part formulation prepared by mixing solid powder and liquid components. The bone repair system was prepared by mixing an aqueous solution of 1-vinyl-2-pyrrolidone VP (46% w/w) and dimethyltoluidine (DMPT) (0.2% w/w) to a dry powdered mixture of PPF (71.8% w/w) and hydroxyapatite (21.6% w/w) to form a viscous putty-like paste. The weight ratio of PPF-VP was kept constant at 3.8. The crosslinking reaction between PPF and VP was initiated by the addition of benzoyl peroxide (3.6% w/w). Free radical generation was accelerated via the use of DMPT in the liquid mixture. Sodium bicarbonate (1.7% w/w) and citric acid (1.3% w/w) were also added to the dry powder formulation. Upon mixing of the VP solution and PPF solids, the reaction of the effervescence agents citric acid and sodium bicarbonate resulted in expansion of the graft material yielding a porous composite with pore sizes of 50 to 500 µm upon cure.

Assessment of Structural Properties

The temporal decrease in mechanical properties was evaluated following in vitro degradation of the cured bone repair material. Cylindrical constructs were immersed in 0.01 M phosphate buffered saline and incubated at 37°C. Experimental sample sizes of 11 cylinders were used for each time point (0, 1, 3, and 6 weeks). At specified times, 3 of the 11 cylinders were removed from the buffer and dried to a constant weight at 50°C. The samples were quick frozen in liquid N2 prior to fracture to preserve pore morphology. Pore architecture and size were determined by scanning electron microscopy. The remaining eight crosslinked-PPF (XL-PPF) cylinders at each time point were removed from the buffer, wrapped in saline soaked gauze, and refrigerated for mechanical analysis.

Pore size of the polymer construct after 0, 6, and 12 weeks of in vitro degradation was measured from scanning electron micrographs (SEM) using Scion Image for Windows, Release Beta 4.0.2.

The mechanical properties of the test materials were assessed to qualify the resorbable bone graft substitute as a replacement or filler for cancellous bone. Test materials were degraded in vitro to simulate physiological conditions. Demineralized bone (Lifenet, Virginia Beach, VA) substituted for autograft in order to simulate the anticipated clinical use of the PPF-based graft substitute. XL-PPF constructs were cut and filed to form uniform cylinders with a length-to-diameter ratio of 2:1. Constructs were tested to failure at a crosshead speed of 0.1 mm/s. Compressive strengths as a function of degradation time and after 3 weeks of in vitro degradation were determined by a one-way analysis of variance (p = 0.003). Thus, mixing the XL-PPF-based graft substitute with 25 percent bone graft did not compromise the mechanical integrity of the implant.

RESULTS

Pore architecture of the bone graft substitute formulation was analyzed for its potential to support tissue ingrowth and osteointegration. The average pore size at 0, 6, and 12 weeks was 170 ± 100 µm, 200 ± 110 µm, and 260 ± 190 µm respectively. The size and number of the larger pores increased with respect to time. The PPF-based bone graft substitute constructs at Week 0 (Figure 1a) consisted of a few larger pores with the majority of pores being fairly uniform in size. Following degradation in vitro, the constructs show a greater number of large pores after 6 (Figure 1b) and 12 weeks (Figure 1c). Macroscopic changes are visible as fissures appear and sections of the polymer detach during the erosion process. Pores in the polymer interior become interconnected as the walls between the pores erode. Pore size of the bone graft substitutes were within the desired range for osteointegration.

NATIVE bone is expected to replace polymer mass lost because of erosion during the concurrent degradation and bone remodeling processes. Initial mechanical properties of the crosslinked PPF-based bone graft substitute (XL-PPF) were comparable to cancellous bone. Peak compressive forces for both XL-PPF formulations were measured through six weeks of in vitro degradation. Initial compressive strengths for XL-PPF with 0 percent demineralized bone (3.5 ± 1.5 MPa) and XL-PPF with 25 percent (w/w) demineralized bone (3.5 ± 4.7 MPa) were comparable to values for human cancellous bone measured under similar conditions (Carter and Hayes 1976). In addition, both formulations retained approximately 50 percent of their initial mechanical strength following 3 weeks of in vitro degradation. Although both formulations had similar compressive strengths through 3 weeks of in vitro degradation, the XL-PPF-based substitute mixed with 25 percent bone had a significantly higher strength (1.9 versus 0.5 MPa) after 6 weeks as determined by a one-way analysis of variance (p = 0.003). Thus, mixing the XL-PPF-based graft substitute with 25 percent bone graft did not compromise the mechanical integrity of the implant.

DISCUSSION

The mechanical properties suggested that the PPF-based bone repair material may provide a clinical alternative to bone graft to initially stabilize bony defects or fractures. The reduction in mechanical strength of the bone repair material is expected to be offset by the mechanics associated with bony recovery. The ability to support bony recovery within this porous, osteoconductive bone repair material has been demonstrated in vivo (Lewandrowski et al. 2002). Studies of bony healing reported that bone recovers 50 percent of its mechanical properties within 3 weeks (Heppenstall 1991). Therefore, the decrease in strength of the PPF-based material approximately balanced the expected strength increase associated with bone recovery.

REFERENCES


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