Development of Bioactive Glass Scaffolds for Segmental Bone Repair

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Statement of Purpose: Many commercial osteogenic filler materials are suitable for repairing contained bone defects, but no satisfactory biological solution to segmental bone loss is yet available. Millions of patients are affected by structural bone loss resulting from trauma, resection of tumors, and congenital diseases. Current treatments (allografts, autografts, and porous metals) are expensive and have limitations. We are developing bioactive glass (BG) scaffolds to meet the need of repairing structural bone loss. BG is of interest in skeletal repair because it is osteoconductive, converts to hydroxyapatite in vivo, and bonds strongly to hard and soft tissues. In this study, BG scaffolds with a grid-like microstructure were created by robotic deposition and tested in multiple loading modes to evaluate their mechanical properties. The capacity of the scaffolds to regenerate bone was evaluated in a rat calvarial defect model.

Methods: BG scaffolds with a silicate composition (13-93) were fabricated using a robocasting technique [1]. The scaffolds (porosity ~50%) had a grid-like microstructure composed of dense glass filaments (diameter = 300 μm), pores of width 300 μm in the plane of deposition (xy plane) and pores of width 150 μm in the z direction (Fig. 1). The strength, elastic modulus, and Weibull modulus of the scaffolds were measured in compression and in flexure as a function of immersion time in simulated body fluid and as a function of implantation time in rat subcutaneous sites. The fatigue resistance was measured in air and in phosphate-buffered saline. Standard procedures were used in the mechanical tests. Scaffolds were implanted for 6 weeks in rat calvarial defects (4.6 mm) to evaluate their capacity to regenerate bone in an osseous defect model. Implantation into the defects followed standard methods [2].

Results and Discussion:

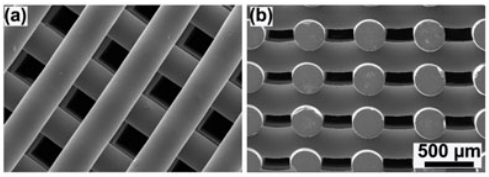

Fig. 1. SEM images of BG scaffolds: (a) plane of deposition; (b) perpendicular to the plane of deposition.

The compressive strength and elastic modulus of the as-fabricated scaffolds were comparable to human cortical bone, but the flexural strength was much lower (Table 1). The Weibull modulus in compression was 12, which was higher than the values (3−10) reported for porous calcium phosphate scaffolds (Fig. 2). The Weibull modulus is a measure of the distribution of strengths; higher values indicate better mechanical reliability. The fatigue life of the as-fabricated scaffolds was ~10^6 cycles when tested in compression under cyclic stresses (2−20 MPa) that are far greater than normal physiological stresses. The brittle mechanical response of the scaffolds in vitro changed to an elasto-plastic response within 2−4 weeks in vivo.

Table 1. Mechanical properties of as-fabricated BG scaffolds and human cortical bone.

	Compression		Flexure	
	Strength (MPa)	Modulus (GPa)	Strength (MPa)	Modulus (GPa)
Scaffolds	86 ± 9	13 ± 2	11 ± 3	13 ± 2
Cortical bone	100−150	10−20	135−190	10−20

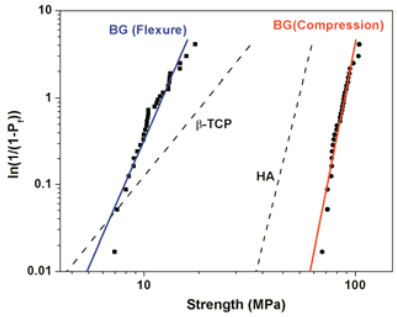

Fig. 2. Weibull plots of the compressive and flexural strength data from the present study. For comparison, plots of the compressive strength for hydroxyapatite (HA) and beta-tricalcium phosphate (β-TCP) are also shhown [3].

Six weeks postimplantation, the BG scaffolds were almost fully infiltrated with new bone (Fig. 3). More than 60% of the available pore space was filled with new bone, which was significantly greater than the values reported for BG scafolds or implants composed of BG particles [4].

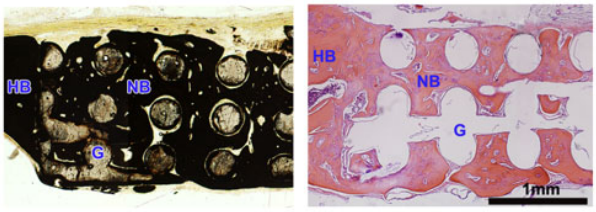

Fig. 3. (*Left*) von Kossa and (*right*) H&E stained sections of BG scaffolds implanted for 6 weeks in rat calvarial defects. (HB = host bone; NB = new bone; G = scaffold).

Conclusion: BG scaffolds prepared by robocasting have compressive strength and elastic modulus comparable to human cortical bone, high mechanical reliability, and excellent fatigue resistance in compression. The scaffolds also have a porous microstructure conducive to bone infiltration in an osseous defect. These scaffolds are promising in the regeneration of loaded bone defects.

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References

[1]Fu et al., Acta Biomater 2011;7:3547-54.
[2]Wang et al., Bone 1998;22:621-8.
[3]Miranda et al., J Biomed Mater Res A 2008;85:218-27.
[4]Bi et al., J Biomed Mater Res A. DOI: 10.1002/jbm.a.34272.