Improved mechanical properties of 3D printed calcium phosphate scaffolds for craniofacial reconstruction

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Statement of Purpose: The free flap autograft is the current gold standard for craniofacial reconstruction, however incurs donor site morbidity, extended operative times, and limitations in reconstructing complex facial geometry. Previously we have shown accelerated allograft remodeling utilizing a tissue-engineered periosteum of hydrogel impregnated mesenchymal stem cells (MSCs) in a murine femoral model (Hoffman MD. Biomaterials 2013;34(35): 8887-8898). To overcome limitations of the allograft, we utilize a 3D powder printing process to build a biphasic calcium phosphate bone scaffold of α-tricalciumphosphate (αTCP) and hydroxyapatite (HA). However, the scaffold demonstrates low flexural strength as well as catastrophic brittle failure with intramedullary pin fixation *in vivo*. Sintering improved flexural strength twofold with minimal reduction of porosity (~2%) as measured by 3-point bend testing and micro-computed tomography (μCT), respectively. Work to improve scaffold toughness using polycaprolactone incorporation is ongoing.

Figure 1. X-ray radiograph scaffold showing failure by fracture on post-operative day 2.

Methods: Biphasic powder printing process using inkjetted phosphoric acid (20wt%) which rapidly dissolves αTCP and re-precipitates as described elsewhere (Inzana JA. Biomaterials, 2013 35(13): 4026-4034). Flexural strength, modulus, and fracture toughness was measured using 3-point bending bar geometry (of 14mm x 4mm x 1mm, MTS-Instron Inc). Sintering was

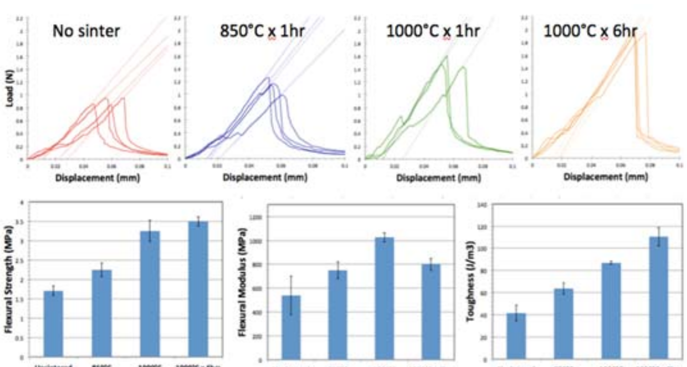

Figure 2. 3pt bend measurement show increased flexural strength and toughness show in with sintering.

performed in an open tube furnace (850°C, 1000°C x 1hr and 1000°C x 6hr). Phase composition was determined using x-ray diffraction (XRD, X'Pert PRO MRD; PANalytical). Microstructure was characterized using scanning electron microscopy. Porosity was determined using μCT. A murine femoral defect model was used to evaluate in vivo behavior of scaffold as described elsewhere (Hoffman MD. Biomaterials 2013;34(35): 8887-8898). X-ray radiography was used to image the scaffold in the femoral osteotomy defect (LX-60 X-ray Cabinet, Faxitron Bioptics LLC).

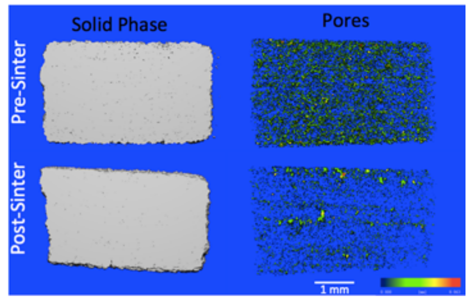

Figure 3. Scaffold μCT shows decrease in porosity with sintering (1000°C for 1hr) scaffold (29.96% to 28.43%)

Results: Early (48hrs) brittle failure of the biphasic scaffolds in vivo using intra-medullary pin fixation (figure 1). Similar failure was quantified in 3pt bend testing, however significant improvements in flexural stress were observed following sintering treatment (850°C, 1000°C x 1hr and 1000°C x 6hrs) (figure 2). The linear relation of strength and toughness suggests no alteration in mechanism of catastrophic failure. However, minimal alteration porosity or pore size distribution was observed following heat treatment (figure 3). XRD confirmed evolution of

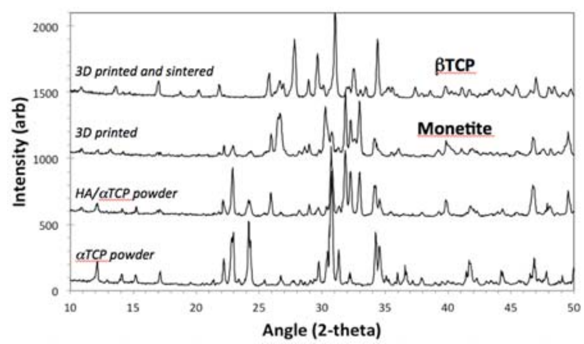

Figure 4. XRD showing evolution of monetite with printing and bTCP with sintering (1000°C x 1hr).

monetite during printing and decomposition of all printed phases with sintering to βTCP (figure 4).

Conclusions: Although powder printing yields porosity, biocompatibility, and precise defect contouring required for craniofacial reconstruction, brittle failure must be mitigated for clinical translation. Herein we report improved flexural strength with sintering with minimal alteration in porosity. Ongoing work includes polymeric composite deposition to optimize fracture toughness as well as microstructural characterization via scanning electron microscopy.