Mechanical Studies of 3D-printed Long-Bone Replacement Scaffolds

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Statement of Purpose: To examine material properties of 3D-printed (direct write) scaffolds used for long bone replacement composed of different hydroxyapatite (HA) and beta tri-calcium phosphate (βTCP) composites, and varied structural configurations. The 3D-printing technique allows scaffolds to be printed exactly to size, shape, and design [1]. In previous studies HA scaffolds produced with this technique have shown excellent bone ingrowth characteristics [2]. Mechanical properties will be an important criteria to determine which composition and structure will be best suited to different surgical and anatomic needs. Long bone replacement/repair will require different designs for different applications or anatomic sites for example femur versus ulna. There are no currently marketed 3D-printed products designed specifically for long bone defects.

Methods: The direct write lattice scaffolds of 60/40, 15/85, and 35/65 % HA/βTCP were tested in compression at a rate of 0.5 mm/min and a modified 3 point bend to determine load to failure and load versus displacement. The scaffolds had varied configurations including % HA/βTCP, sintering temperature (1100°C - 1200°C), strut diameter (150 – 250 μm), porosity of struts (0-50% fugitive material), pore size (250-400 μm), presence/absence of a cortical shell, and overall design (lattice versus ring design, Figure 1). Ultimately these scaffolds will undergo cyclic load (fatigue).

Results: Compression testing indicated that the 60/40 HA/ βTCP scaffolds showed higher stiffness (312.73±39.74 N/mm) in comparison to 15/85 HA/ βTCP, fired at 1200°C (272.93±9.99) or at 1100°C (416.82±22.21). The lattice scaffolds which were composed of 0%, 25%, and 50% fugitive material also had supporting cortical shells. These showed increased strut porosity but higher stiffness (first two groups), with slopes of 1300.16±83.76, 1358.5±13.69, and 125.39±7.21 correspondingly. The scaffolds with an open ring design showed increased stiffness in the 60/40 HA/ βTCP (652.19±118.61) when compared with the 15/85 scaffold of the same configuration (190.65±11.08). When the open pore designs (no cortical shell) were compared, the 60/40 HA/ βTCP (280.57±44.33), showed lower stiffness than the15/85 HA/ βTCP (426.39±54.74). The scaffolds with the outer cortical shell design of the 60/40 and 15/85 HA/βTCP composite had slopes of 332.10±72.55 and 397.30±43.45 respectively. Some scaffolds with the cortical shell design showed no crack initiation as high as 800N. The increased sintering temperature increased the density of the scaffolds resulting in higher strength. However, other preliminary studies in same lab show that less density and less HA% shows much improved resorption *in vivo.* There appears to be an inverse relationship between strength and resorption rate.

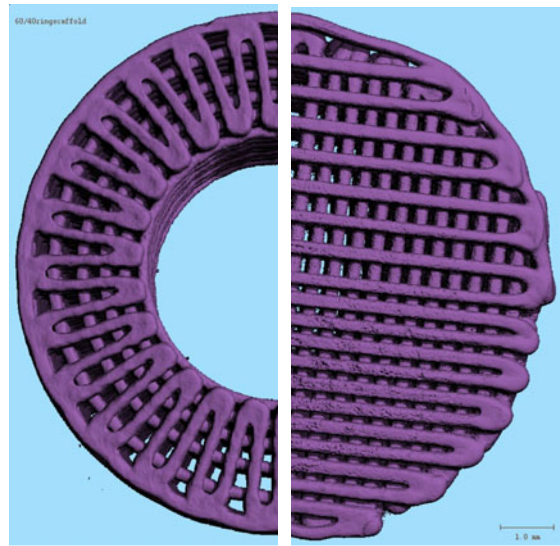

Figure 1. microCT images of an open ring 60/40 HA/ βTCP scaffold (left), and a lattice 15/85 HA/βTCP scaffold (right).

Conclusion: The 60/40 HA/βTCP scaffolds are generally stiffer than the 15/85 HA/βTCP scaffolds with the same structure and sintering temperature. Differences were observed when comparing the open pore and outer ring designs, and in this case the 15/85 HA/βTCP showed higher strength compared to the 60/40 HA/βTCP. In most cases increasing the hydroxyapatite content increased stiffness, strength, and stability, but the higher HA content has resulted in less remodeling in other experiments. The outer supporting shell increases the strength but may act as a barrier to ingrowth of tissue and vasculature. Introduction of the fugitive material increased porosity and decreased strength. Because different strength and remodeling characteristics will be required for various applications, these results will lead to better designs for individual bone repair needs.

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