Process-Structure-Quality Relationships of 3D Printed Tissue Engineering Scaffolds

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Motivation and Objective

Motivation: 35% of deaths in the United States alone could be prevented with a large enough supply of viable organs, and Bio-AM may make that a reality. However, suboptimal printing parameters lead to defective prints, incapable of transplantation.

Goal: Enable flaw-free Bio-AM of tissues by understanding and quantifying the causal thermal and flow phenomena that lead to defects.

Objective: Create and implement a methodology to assess and optimize printability.

Bone material (hydroxyapatite, HAp) was mixed with a thermoplastic polymer (polycaprolactone, PCL).

Suboptimal printing parameters and material composition lead to defective prints.

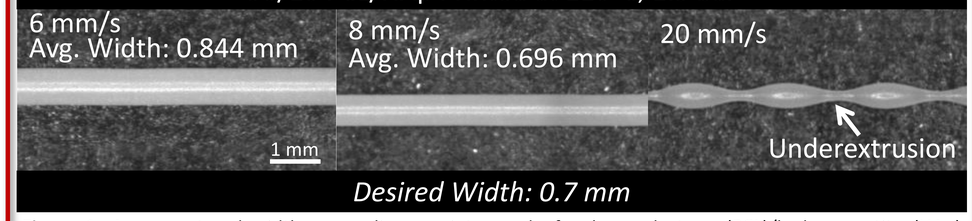

Figure 1: Average strand width versus linear print speed of polycaprolactone (PCL)/hydroxyapatite (HAp) composition.

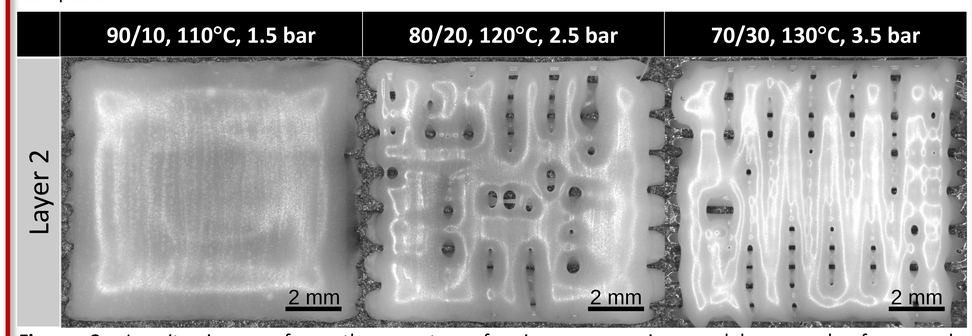

Figure 2: *In situ* images from the worst performing compressive modulus sample from each polycaprolactone/hydroxyapatite composition at the lowest and highest printing condition arrangements.

Experiment Setup

Bio-AM setup with in-situ imaging for the monitoring of tissue scaffolds.

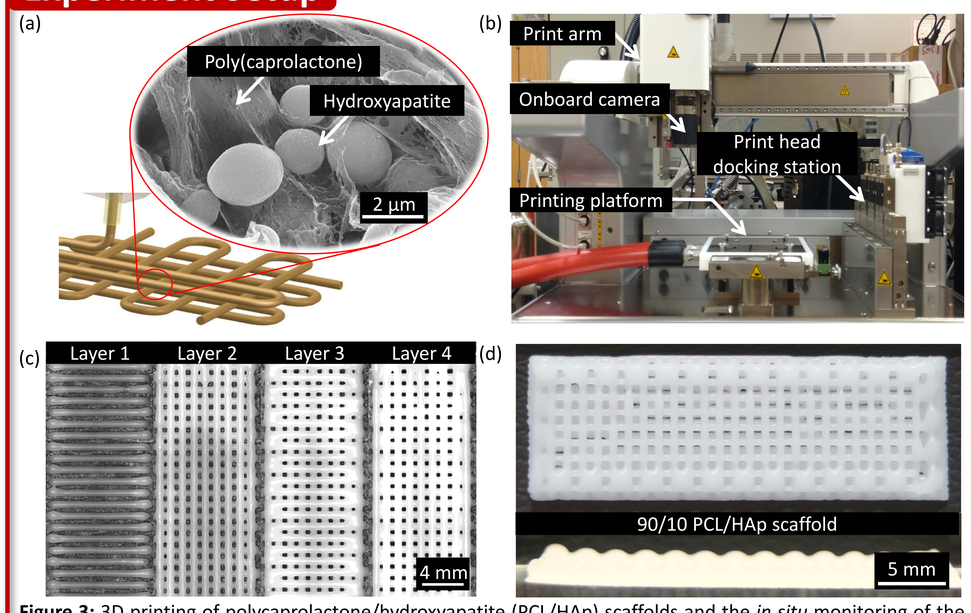

Figure 3: 3D printing of polycaprolactone/hydroxyapatite (PCL/HAp) scaffolds and the *in situ* monitoring of the geometrical outcome. (a) Schematic of PCL/HAp printing and microstructure of interspersed HAp particles in the thermoplastic PCL. (b) Print setup of the bioplotter used in the study and the location of the camera for *in situ* monitoring of the printing process. (c) Layer by layer images generated through *in situ* monitoring. (d) A representative image of a 3D printed PCL/HAp scaffold with clinically relevant dimensions.

Results

Physical and biological properties are functions of temperature, pressure, velocity, composition, and shape.

(1) Bone tissue composite is shear thinning (need to balance between temperature and extrusion pressure).

(2) Adding bone material (HAp) increases viscosity. (3) Increasing bone material (HAp) improves bone growth.

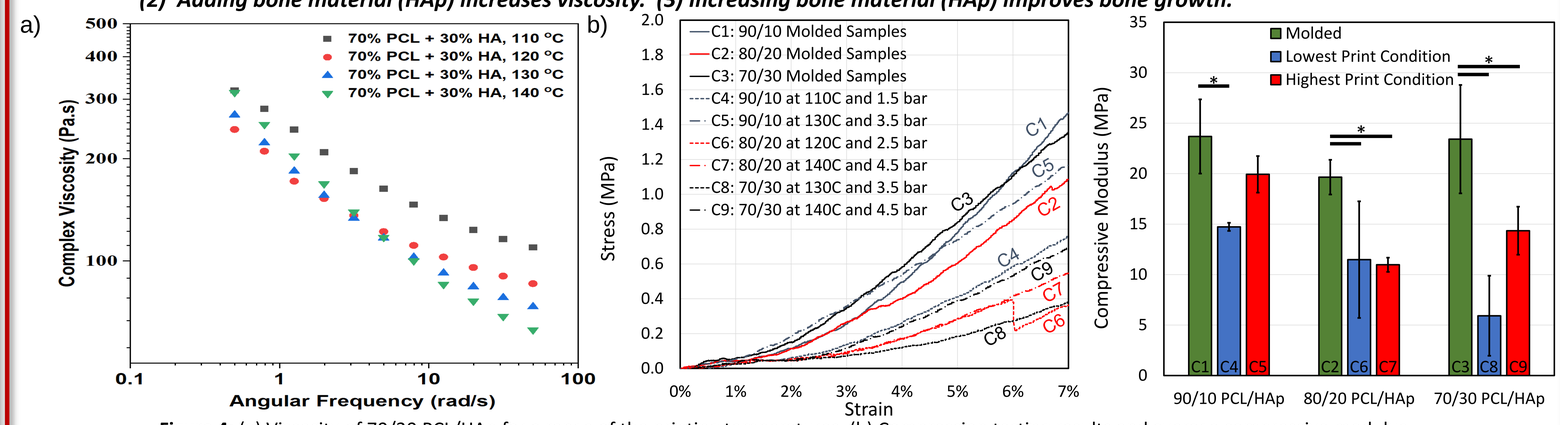

Figure 4: (a) Viscosity of 70/30 PCL/HAp for a range of the printing temperatures. (b) Compression testing results and average compressive modulus.

A viable construct must have high fidelity at both the strand and geometry levels.

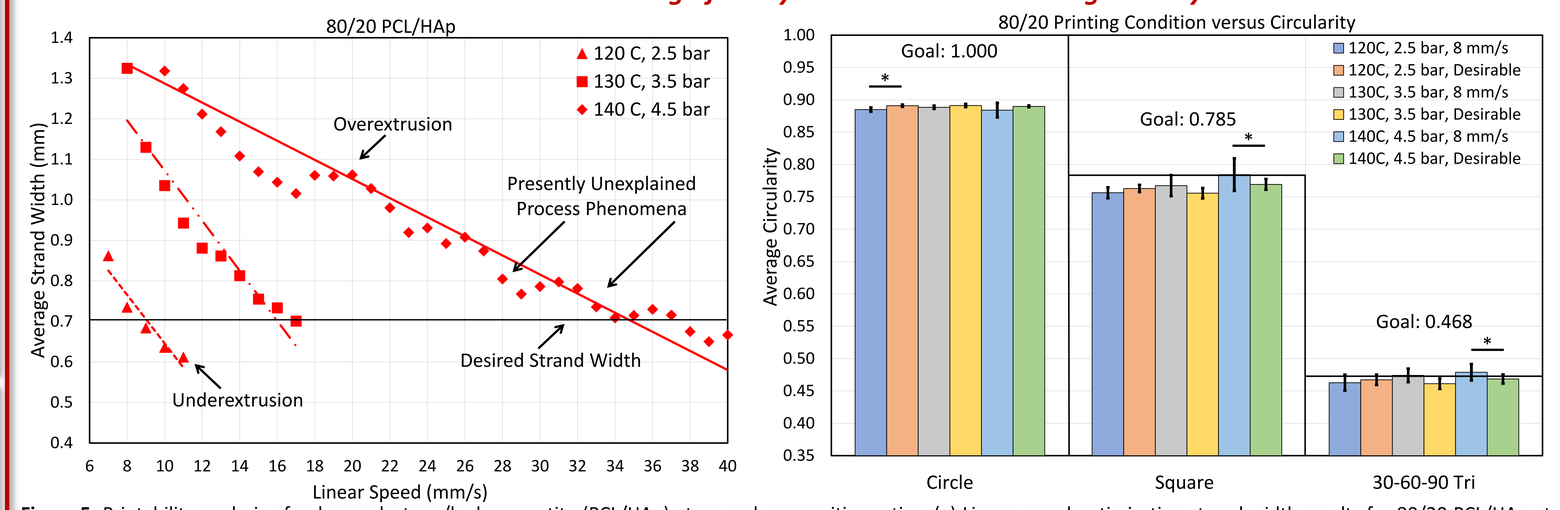

Figure 5: Printability analysis of polycaprolactone/hydroxyapatite (PCL/HAp) at several composition ratios. (a) Linear speed optimization strand width results for 80/20 PCL/HAp at different printing temperature/pressure conditions. (b) Geometric quality of 80/20 PCL/HAp printed at various linear print speeds and printing temperature/pressure combinations.

Bone growth is governed by material composition and scaffold quality.

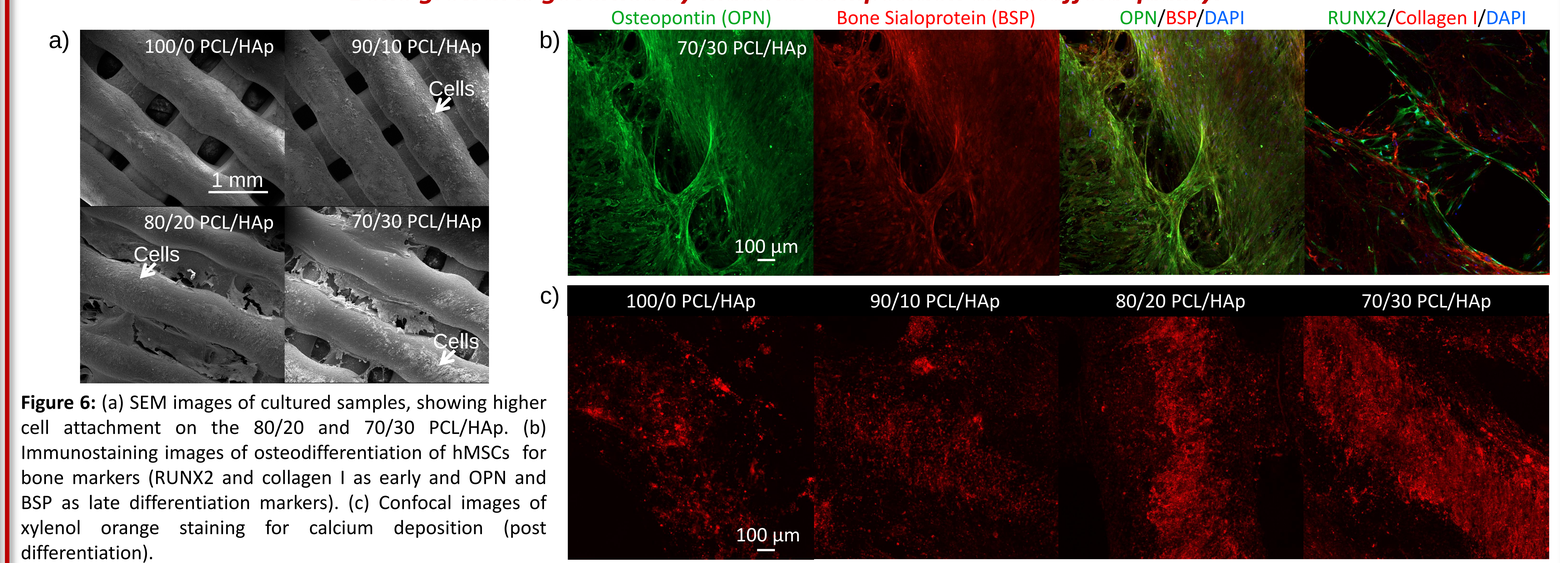

Figure 6: (a) SEM images of cultured samples, showing higher cell attachment on the 80/20 and 70/30 PCL/HAp. (b) Immunostaining images of osteodifferentiation of hMSCs for bone markers (RUNX2 and collagen I as early and OPN and BSP as late differentiation markers). (c) Confocal images of xylenol orange staining for calcium deposition (post differentiation).