3D Biomaterial Scaffolds Exhibiting a Tunable Negative Poisson's Ratio

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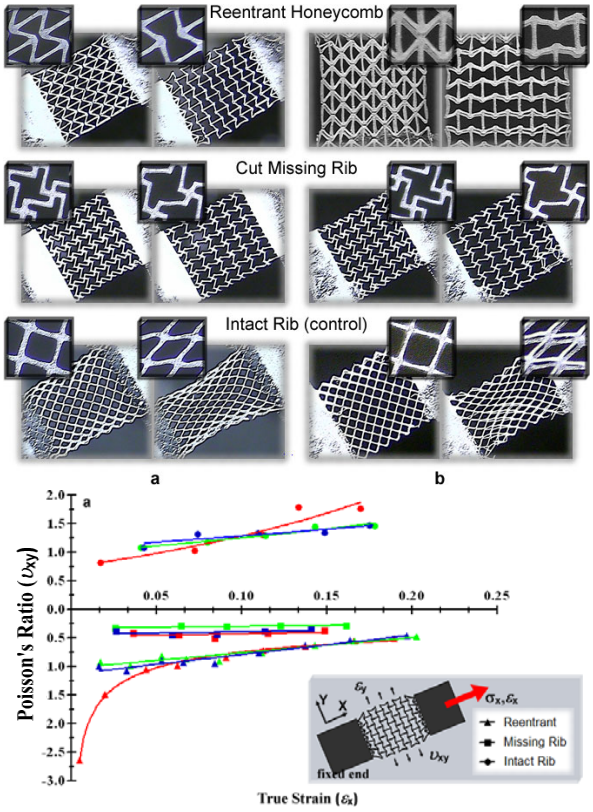
Statement of Purpose: While elastic modulus is tunable in scaffolds, the Poisson's ratio of virtually every porous tissue construct is positive i.e., it contracts in the transverse direction upon expanding in the axial direction. In some applications, scaffolds having a negative Poisson's ratio (auxetic behavior) may be more suitable for emulating the behavior of native tissues and accommodating and transmitting forces to the host tissue site [1]. Current methods to fabricate auxetic foams render little practical control over the cellular microstructure, making it very difficult to tune the strain-dependent behavior of Poisson's ratio. In tissue engineering, one must have the capability to precisely tune the magnitude and polarity (positive or negative) of Poisson's ratio in three-dimensional constructs to match the properties of the specific tissue being regenerated. Moreover, such command over Poisson's ratio must also be attainable in biologically-relevant materials. Here we report three-dimensional polyethylene glycol tissue constructs having tunable negative Poisson's ratios.

Methods: Auxetic behavior was achieved by patterning specially-arranged unit-cellular structures. AutoCAD LT was used to design the 2D scaffold layers with Unit-cell geometries and spatial-arrangements taken from existing analytical models that predict strain-dependent negative Poisson's behavior [2,3]. 3D simulations were conducted for each unit-cell type (reentrant, missing rib, and intact rib unit-cells). 3D scaffolds were fabricated by stacking single-layer constructs, by digital micro-mirror device projection printing (DMD-PP) system. The PEG constructs were loaded into a homemade strain measurement system. Experimental results were compared with analytical models.

Results: Figure illustrates the mechanical responses of the single-(Fig. a) and two-layer (Fig. b) constructs resulting from the application of the axial tensile load. The side-by-side optical images show the constructs in their undeformed and strained states, and were taken from one of the three tests performed for each unit-cell. The Poisson's ratios of the single-layer reentrant and missing rib constructs were negative while the intact rib construct (used as a control) was not-auxetic for the values of true strain that were tested (0-0.2) (Refer Fig. Plot - color represents separate experiments). Because PEG is not auxetic, our results show that unit-cell shape induces auxetic behavior as predicted by analytical. The experimental Poisson's ratios for the single-layer reentrant construct decreased linearly (in magnitude) from approximately -1 to approximately -0.5 for increasing values of true axial strain from 0-0.2 (Refer Plot), very similar to those predicted by the analytical model (-1 to -0.7) for axial strains of 0-0.2.

The missing rib structure demonstrated Poisson's ratios of about -0.3 to -0.5 (Refer Plot), which showed that the Poisson's ratio stayed relatively constant for the range of axial strains tested in our experiments. Our results agree closely with the model reported by Gaspar et al [2].

In comparing the single-layer data among the three strain tests performed for each unit-cell geometry, Poisson's ratios appeared to be quite consistent (Refer Plot). Some variability existed, as expected, likely because of the fact that each experiment was performed with a different sample. Small, yet unavoidable, differences in the samples were likely introduced during DMD-PP fabrication, which would have imposed some differences in elasticity. Strain testing using 2-layer PEG scaffolds **(Figures b)** appeared to have little influence on Poisson's ratio. (Data not shown)



Conclusions: Geometry and spatial arrangement of the pores (unit-cell) controlled the polarity and magnitude of the Poisson's ratio of the overall meshworks. The strain-dependent behavior was well-predicted by stress-strain analytical models. This work demonstrates the ability to tune negative Poisson's ratios by virtue of their well-defined cellular meshworks.

References:

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