Elastically Anisotropic Phantoms Constructed from 3D-printed PLA Fibers

Kristyna Herman[1], Gabriela Torres[1], Keita Yokoyama[1], Caterina M. Gallippi[1]
[1]Joint Department of Biomedical Engineering, University of North Carolina and North Carolina State University, Chapel Hill, NC, USA

Background

Many tissues including muscle, kidney, and breast are elastically anisotropic. Improperly considered, elastic anisotropy may confound elasticity imaging. However, if appropriately exploited, elastic anisotropy can be a relevant biomarker. To experimentally evaluate an elasticity imaging method's performance in mechanically anisotropic materials, calibrated tissue-mimicking phantoms are needed. The objective of this work is to demonstrate the feasibility of constructing mechanically anisotropic phantoms using 3D-printed PLA fibers embedded in gelatin or polyvinyl alcohol (PVA) cryogel.

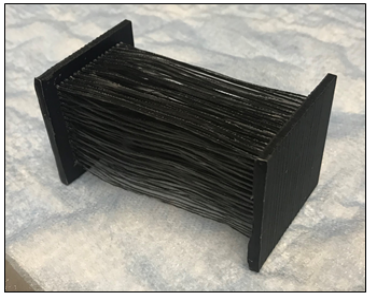
Methods

PLA fibers were 3D-printed with individual fiber strands being 0.4 x 0.4 mm2 in cross-section, spaced 0.6mm apart, with a total of 30 fibers per row. Four identical fiber sets were constructed; two were embedded in gelatin and two in PVA. Gelatin and PVA elasticities were targeted to 15 kPa and 30 kPa using established recipes [Physics in Med & Biol, 50(23) 5597-5618 (2005)], [Physics in Med & Biol, 59(22), 6923-6944 (2014)]. ARFI imaging was performed on the constructed phantoms using a Siemens S3000 scanner and a 9L4 transducer attached to a computerized rotation stage that enabled data acquisitions at 0°, 30°, 60°, and 90° concentric orientations, where 0o and 90o corresponded to the long-axis of a spatially asymmetric ARF excitation being aligned across and along the fibers, respectively. Degree of anisotropy (DoA) was calculated as the ratio of peak displacements at 90° versus 0° orientations.

Results and Discussion

Panel (a) depicts a representative fiber set. Panels (b-d) show that PDs were smaller in the 0° versus 90° orientation, and DoAs were greater than 1.6, in all four phantoms. While both gelatin and PVA embedded fibers demonstrated elastic anisotropy, DoA values were 32% higher in gelatin versus PVA phantoms. These pilot experimental results demonstrate that phantoms constructed of 3D-printed PLA fibers embedded in gelatin or PVA exhibit elastic anisotropy as assessed by ARFI ultrasound. Future work will investigate how fiber size and spacing impact mechanical anisotropy.

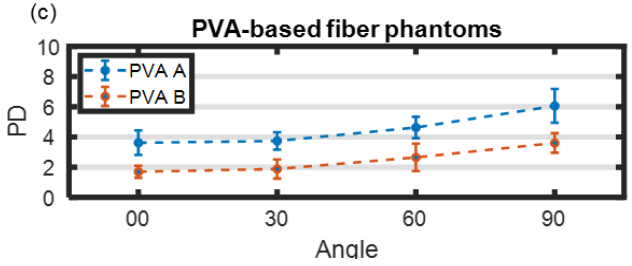
(a)



(b)

Phantom	Gelatin [%w]	PVA [%w]	ARFI Peak Displacement [μm]				
			0°		90°		Degree of Anisotropy
			Median	StDev	Median	StDev	
A		10.50	3.62	0.81	6.06	1.12	1.67 ± 0.68
B		21.00	1.70	0.39	3.61	0.65	2.12 ± 0.87
C	6.48		3.76	0.59	8.90	1.54	2.37 ± 0.78
D	8.95		2.33	0.79	6.17	0.92	2.65 ± 1.29

(c)



(d)

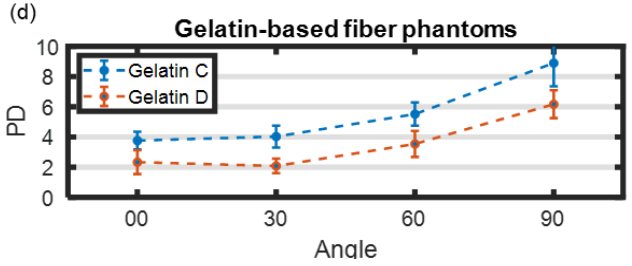


Figure 1 shows (a) 3D-printed PLA fibers used for all phantoms, (b) ARFI PD results for both the gelatin- and PVA-based fiber phantoms, including the degree of anisotropy, and PD versus angle for PVA- (c) and gelatin-based (d) phantoms.

Joint Department of BIOMEDICAL ENGINEERING UNC CHAPEL HILL NC STATE UNIVERSITY