Joint Department of
BIOMEDICAL ENGINEERING
UNC CHAPEL HILL
NC STATE UNIVERSITY

Mechanically Anisotropic Tissue Mimicking Phantoms for Development of Ultrasonic Imaging Protocols

Varsha Venkatapathy[1], J. Aidan Armstrong[1], Sabiq Muhtadi[1] and Caterina M. Gallippi[1]
[1]Joint Department of Biomedical Engineering, University of North Carolina at Chapel Hill and North Carolina State University, NC, USA

GALLIPPI ULTRASOUND LAB
ULTRASONC Ultrasound Research Association of North Carolina

Motivation and Hypothesis

•Noninvasive imaging techniques are needed to assess mechanical anisotropy in tissues like muscle, kidney, and breast.
•Tissue-mimicking phantoms serve as valuable experimental models to evaluate imaging methods in interrogating mechanical anisotropy.
•This study aims to demonstrate the feasibility of constructing mechanically anisotropic phantoms using 3D-printed polylactic acid (PLA) fibers embedded in the viscous fluids of cornstarch and milk.
•-We hypothesize that phantoms constructed with PLA fibers embedded in viscous fluids of cornstarch or milk will exhibit mechanical anisotropy, detectable through variations in displacement induced by spatially asymmetric Viscoelastic Response (VisR) ultrasound excitations at different orientations relative to the embedded fibers.

Phantom Preparation

A. Phantom Preparation
In our experiments, tissue characteristics were simulated using poly(lactic acid) (PLA) fibers. These fibers were produced using a 3D printer, with a cross-sectional area of 0.4 x 0.4 mm² and a spacing of 0.6 mm between fibers. Each phantom consisted of 30 fibers per row. To ensure stability during printing, we utilized Ultimaker PVA as a water-soluble support material, which was dissolved post-printing.
For our study, we prepared two phantoms, each with distinct backgrounds:

1. Milk-Embedded Phantom:
One phantom was embedded in milk, chosen for its viscosity and ability to provide a stable medium for embedding without introducing significant air bubbles. Milk's viscosity aids in maintaining structural integrity during the embedding process, ensuring uniformity and minimizing artifacts in imaging.

2. Cornstarch-Water Solution-Embedded Phantom:
The second phantom was embedded in a cornstarch-water solution, also selected for its viscous properties. This solution effectively suspends the PLA fibers without trapping air bubbles, allowing for clear and accurate imaging. The viscosity of the cornstarch-water solution contributes to stable phantom construction, enabling precise experimentation without interference from imaging artifacts.

By opting for these viscous mediums, we aimed to create phantoms that offer reliable tissue simulations while facilitating optimal imaging conditions for accurate experimental results.

Imaging Protocols

B. VisR Ultrasound
VisR ultrasound applies acoustic radiation force to induce tissue displacement, which is detected and analyzed to generate images depicting tissue mechanical properties. For this study, we utilized VisR relative elasticity (RE) measurements, which provide an indication of the underlying shear elasticity of the material under observation relative to the applied force amplitude.

- Relative Elasticity Quantification
With VisR, we quantified the relative elasticity of the phantoms. This involved measuring the response of the tissue to induced stress, allowing us to generate precise elasticity maps. These maps provide a detailed representation of how elasticity varies within the phantom, highlighting regions of interest and potential anisotropy.

- Rotation Angle Imaging
Each phantom was imaged twice, with first the transducer placed 15 mm above the phantom, and then the transducer placed 5 mm above the phantom. To comprehensively understand the directional variation of shear elasticity within the phantoms, we performed imaging starting with the transducer oriented across the phantom fibers (0°), then moving the transducer by 30° increments till we traversed the full 180°. At each rotation angle, VisR imaging was performed, and a region from the corresponding RE map was analyzed to map out how the underlying elasticity varied with rotation angle.

Table I: Transducer Parameters

Parameter Name	Value
Transducer	Siemens 9L-4
Focal depth	30 mm
Excitation Center frequency	4.21 MHz
Excitation F/#	1.5
Tracking center frequency	6.15 MHz
Tracking Transmit F/#	1.5
Tracking Receive F/#	0.75
Tracking PRF	10 KHz

Fig 1. Illustrates the experimental setup employed for imaging the water-based embedded phantoms. On the left, the transducer positioning atop the phantom is depicted. On the right, a B-mode representation is presented, offering a two-dimensional grayscale visualization of the internal structure within the focal region.

Results

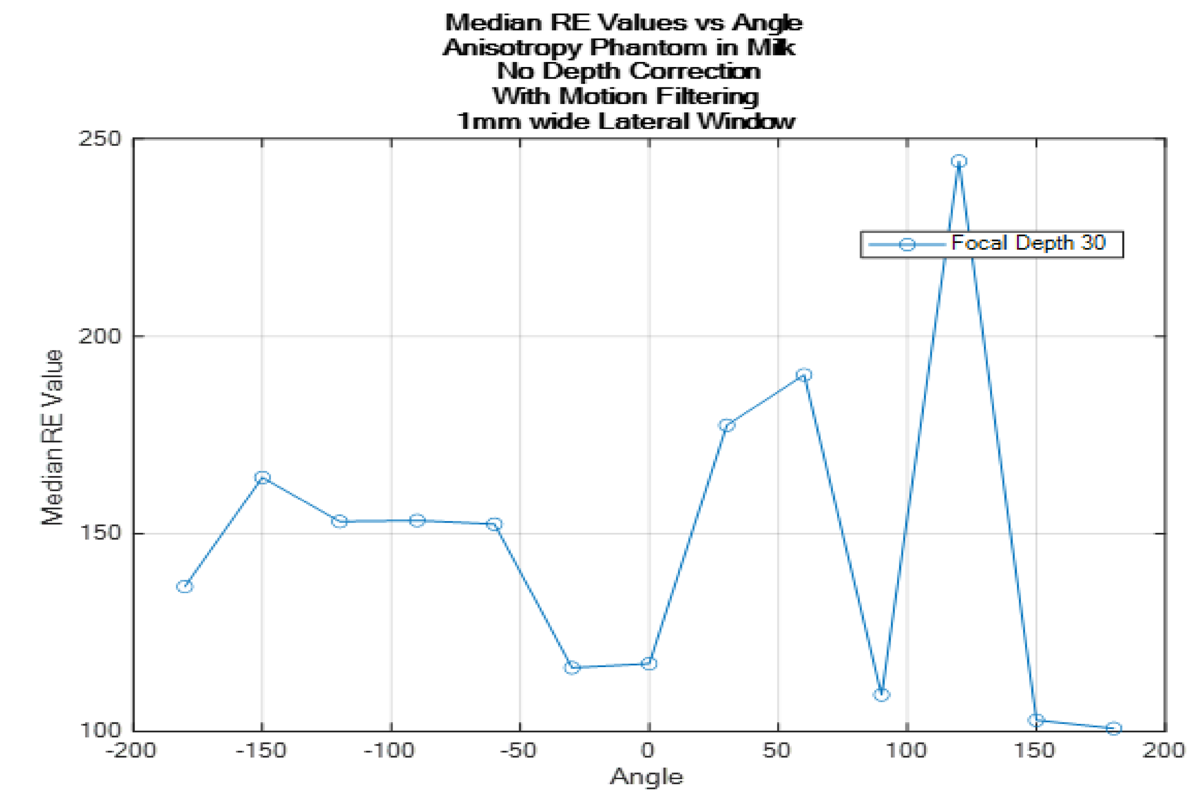

Fig 2: Variation of Relative Elasticity Values Across Phantom Angle Rotations (-180° to 180°) in Milk-Embedded Phantom Imaging: Assessing Anisotropy.

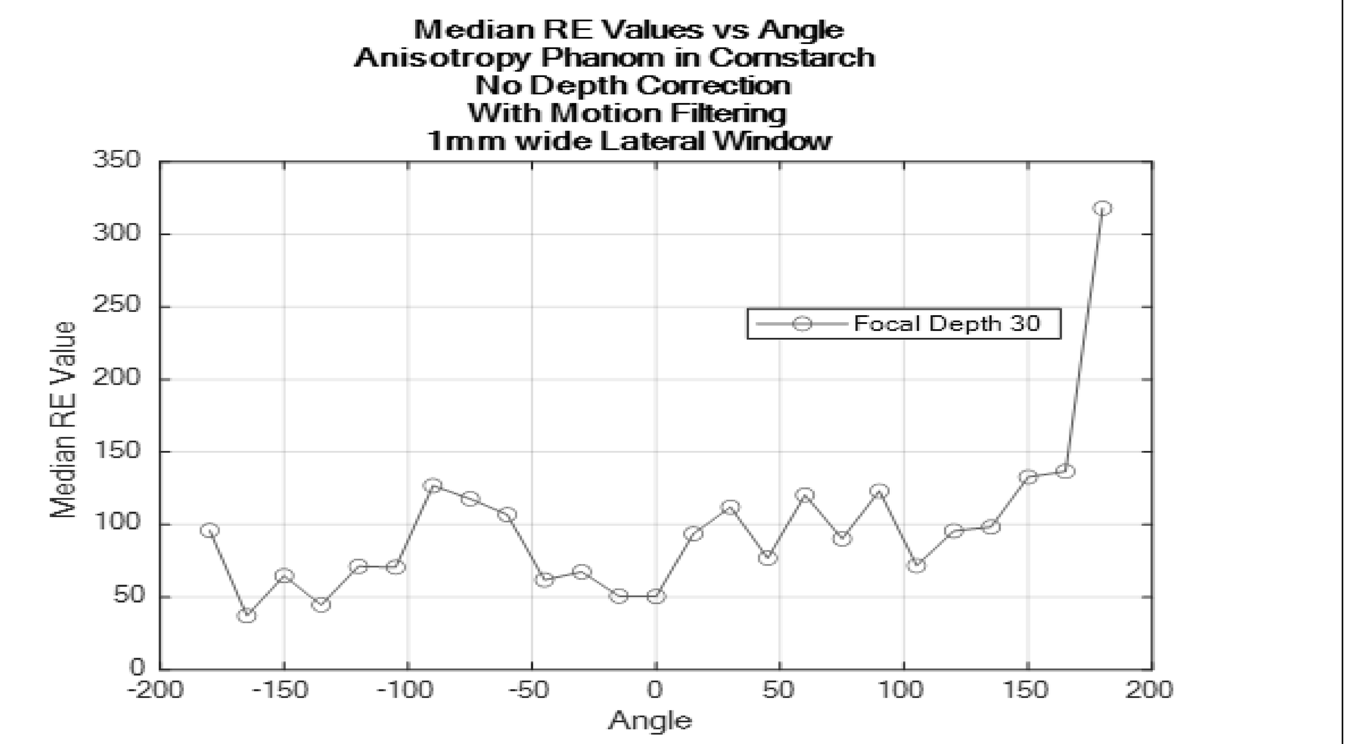

Fig 3: Variation of Relative Elasticity Values Across Phantom Angle Rotations (-180° to 180°) in corn starch-embedded Phantom Imaging: Assessing Anisotropy..

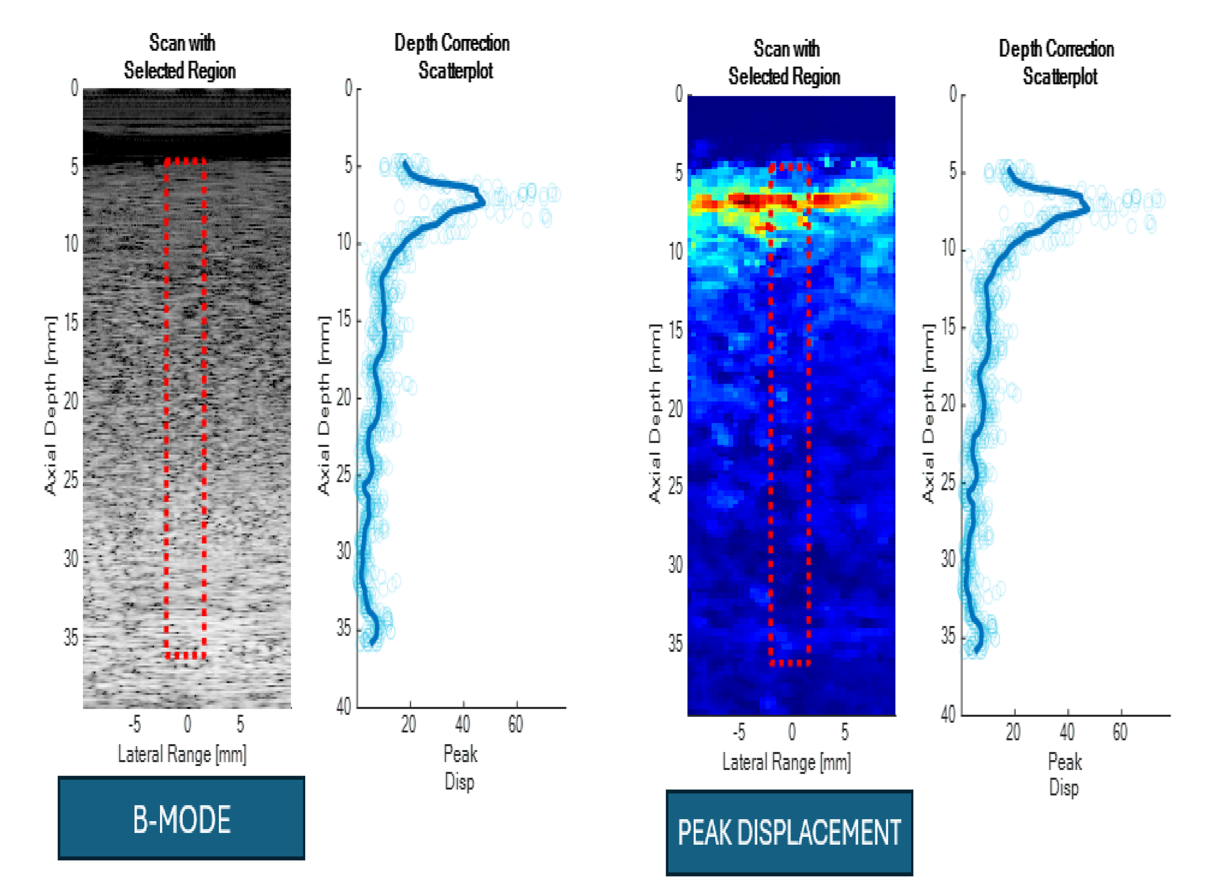

Fig.4 Peak Displacement Axial Distribution with Phantom 5 mm away from Transducer focus at 30 mm.

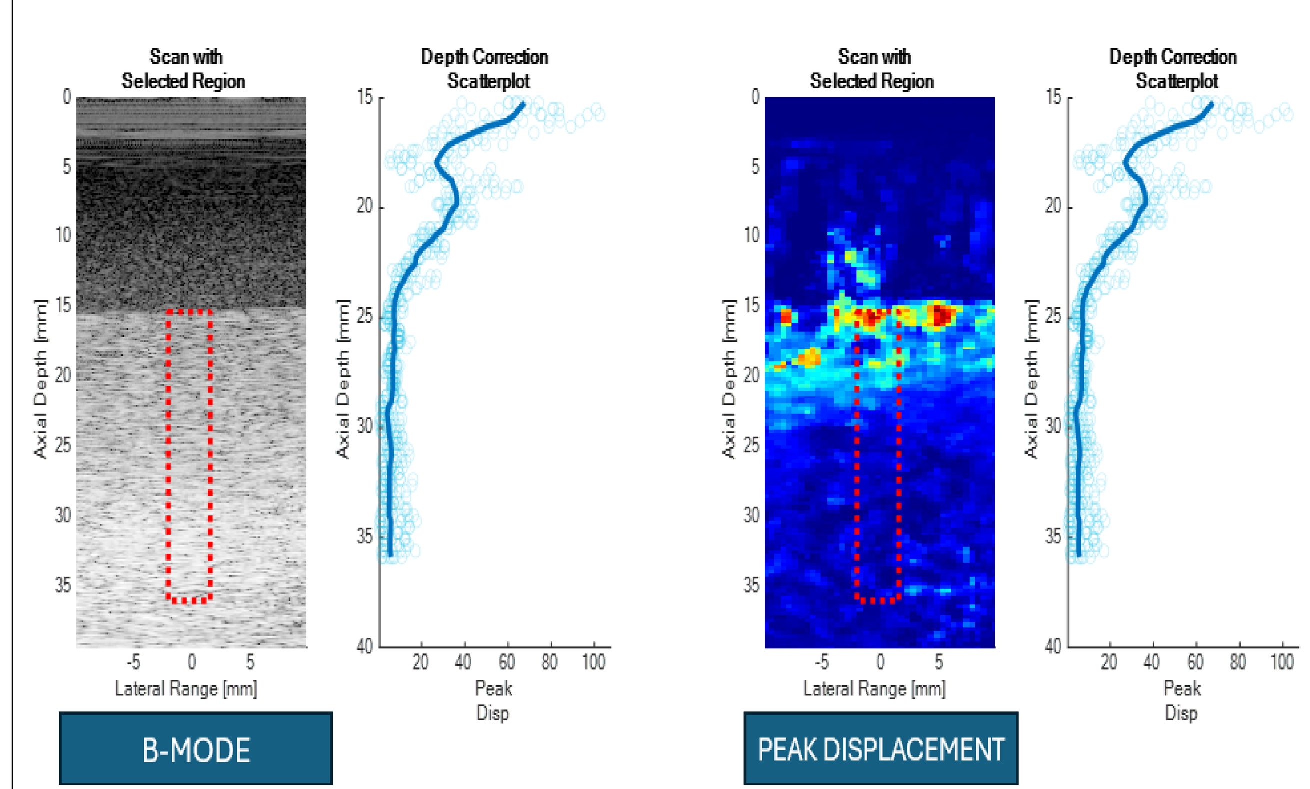

Fig.5 Peak Displacement Axial Distribution with Phantom 15 mm away from Transducer focus at 30 mm.

Conclusion

- Initial attempts with a gelatin embedded phantom failed due to air bubble-induced signal distortion.
- Despite observing potential anisotropy in Figures 1 and 2, conclusive findings were lacking,
- Unexpectedly, each imaged angle revealed different Relative Elasticity (RE) values, diverging from the anticipated sinusoidal trend.
- Inconclusive results were attributed to disparities between peak displacement alignment and the intended focus depth at 30 mm.
- Initially imaged at 15 mm and later at 5 mm, the phantom failed to align peak displacement with the focal depth despite closer proximity to the transducer, likely due to material properties.
- It was expected for the peak displacement to align with the focal depth of the transducer, particularly when imaged closer to the phantom, as there would be more direct and focused delivery of ARFI excitations.
- The rigid and smooth surface of Polylactic Acid (PLA) in the phantom caused reflection rather than transmission of sound waves, contributing to experimental discrepancies.
- Additionally, contrasting mechanical properties between the water-based solution and the phantom hindered the translation of Acoustic Radiation Force, affecting force transfer between mediums.
- Future experiments necessitate redesigning the phantom using materials with enhanced sound transmissivity.
- Integration of alternative imaging methods, akin to gelatin, could provide insights into anisotropy across phantoms with varying Young's moduli, improving tissue representation.

References

[3] M.M. Hossain and C.M Gallippi, "Electronic point spread function rotation using a three-row transducer for ARFI-based elastic anisotropy assessment: in silico and experimental demonstration," IEEE Trans. Ultrason. Ferroelectr. Freq. Control, vol. 68, no.3, pp. 636-646, 2017.