Oil-Gelatin and PVCP Phantom Materials for Ultrasound Elastographic System Testing: Feasibility of 3D Printing

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Introduction

- **Ultrasound Elastography (UE)**

UE system testing using tissue-mimicking phantoms is essential for proper system characterization & performance evaluation.

Current UE phantoms such as those simulating the breast are generally homogenous with simple inclusions unlike heterogeneous breast tissue and irregular breast masses.

3D printing is an attractive technique for creating complex tissue mimicking phantoms. Several critical factors making a material suitable for 3D printing at proper resolution:

- Melting point, Solidification speed and cooling viscosity

Three promising Tissue Mimicking Material are

- Gelatin-Oil, Polyvinyl alcohol (PVA) and Polyvinyl Chloride Plastisol (PVCP).

Explore 3D-printability of PVCP and oil-gelatin materials for tissue mimicking phantoms

- Define materials melting point/viscosity characteristics for compatibility with 3D printing
- Test acoustical/mechanical properties before and after printing for stability.

Fabricate complex breast tissue mimicking phantoms

- More realistic anatomic structure
- Better simulate variation in breast size/density

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Methods I

I. Phantom Material Fabrication

- Tissue-mimicking phantoms should exhibit the same mechanical and acoustic properties the same as tissue
- Formulations Simulating the Two Main Breast Tissue Types :
  - Fibroglandular Tissue
  - Fatty Tissue

Tunable Polyvinyl Chloride Plastisol (PVCP)

- Adjusting of Mechanical and Acoustic Properties
- PVC Resin Proportion
- Plasticizer Proportion
- benzyl butyl phthalate (BBP)
- Di(2-ethylhexyl) adipate (DEHA)
- Glass Beads Added to Control Backscattering

Breast tissue type simulated	BBP (v/v)	DEHA (v/v)	PVC (m/m)	Beads (mg/mL)
Fatty (Pf)	42%	58%	8.4%	10 (38-63µm)
Glandular (Pg)	87%	13%	8.6%	30 (63-75µm)

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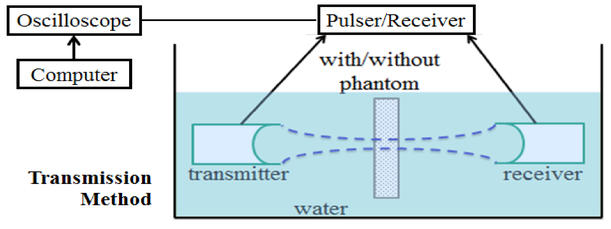
Methods II

Oil-Gelatin Tissue Mimicking Phantom Formulation

Tissue Simulated	Safflower Oil	Surfactant	Formalin	Thimerosal
Fatty	50% of Gelatin Emulsion	15 cc per Liter of Oil	0.7 cc per 100 cc of gelatin	1 gram/liter
Fibroglandular	30% of Gelatin Emulsion	15 cc per Liter of Oil	0.7 cc per 100 cc of gelatin	1 gram/liter

II. Acoustic and Mechanical Characterization

Through Transmission Method

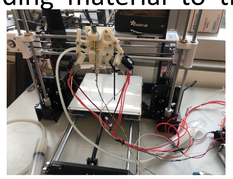


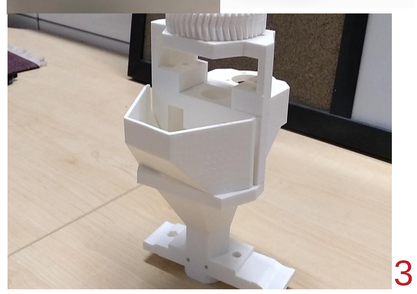
Transmission Method

Mechanical testing device(MicroTester, ADMET, Norwood, MA)

III. 3D Printing

- Printer: Rep rap opensource Prusa i3 MK2S
- Have a custom made drill feed setup with 3D printed parts to make it plausible to push the material through the extruder
- Create pellets from the fabricated phantoms and will be pushed to the nozzle
- Use a syringe system as a second option of feeding material to the nozzle





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Results

Melting Point

Phantom Type	Start Melting (°C)	Fully Melted (°C)	Solidification (°C)
PVCP	98	135	53
Gelatin	51	67	35.5

Acoustic Characterization Before And After Melting

Phantom Material Type	Before Melting		After Melting		In-Vivo Acoustic Properties Values
	Speed of Sound (m/s)	Acoustic Attenuation (dB/cm/MHz)	Speed of Sound (m/s)	Acoustic Attenuation (dB/cm/MHz)	Sound Speed (m/s) 1540
Oil-Gelatin Fat	1500	0.5	1500	0.5	Attenuation Coefficient ($dB^{-1}cm^{-1}MHz^{-1}$) 0.5-0.7
Oil-Gelatin Glandular	1520	0.4	1520	0.4	Frequency Range (MHz) 2 -15
PVCP Fat	1540	0.8	1540	0.8	
PVCP Glandular	1540	1.1	1540	1.1	

Mechanical Characterization Before And After Melting

Phantom Material Type	Before Melting	After Melting	Tissue Young's Modulus at 5% Compress
	Young's Modulus (KPa)	Young's Modulus (KPa)	Fat 4.8
Oil-Gelatin Fat	8.2	8.9	
Oil-Gelatin Glandular	12.3	12.6	Glandular 17.5
PVCP Fat	6.4	7.1	
PVCP Glandular	9.4	9.6	

- Mechanical and acoustic properties of the PVCP and Gelatin-Oil material before and after melting was almost the same
- These material are an ideal candidate for the 3D printing

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Future Work

Fabricate 3D printed complex phantom to mimic the breast types with different tissue compositions.

- Attempt a complex breast phantom using 3D printing and a 3D breast tissue model derived from CT
- Comparison of the 3D printed breast phantom with commercially available ones (CIRS and Blue phantom)

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