3D Thermo-Acoustic Modeling of a Piezoelectric Transducer for Directed Interstitial Ultrasound Ablation

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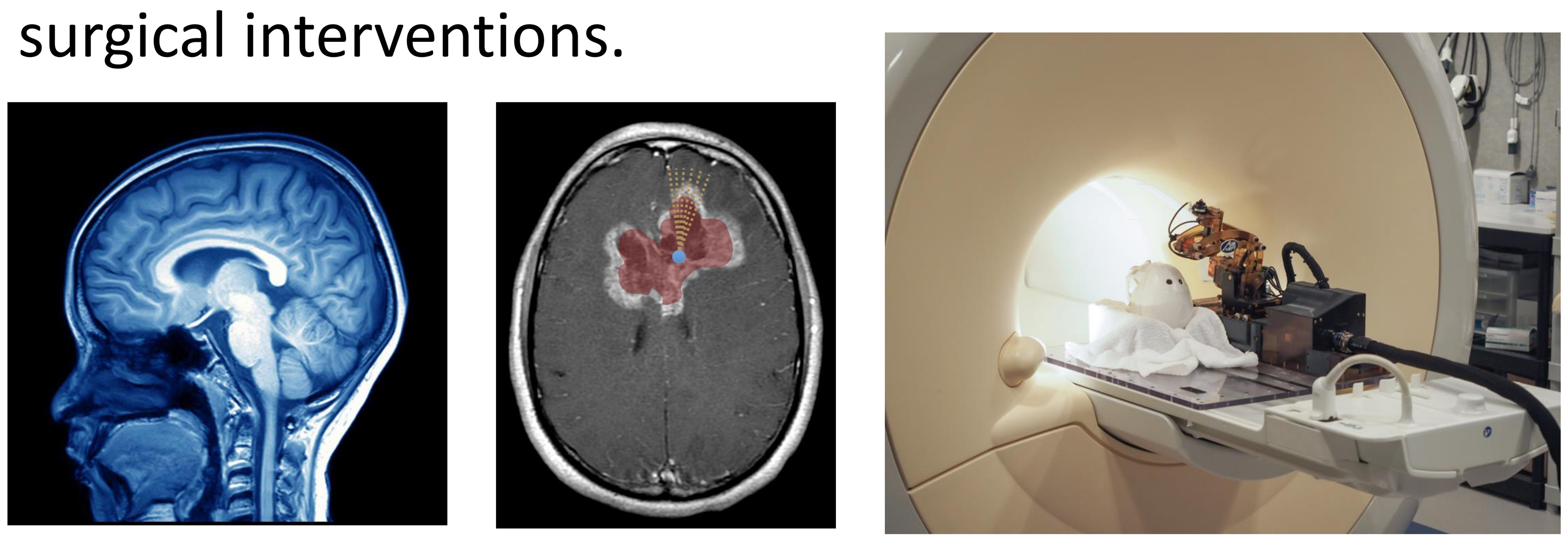
INTRODUCTION: Cancer is a healthcare concern worldwide, with a projected 1,762,450 new cases in the United States for 2019 [1]. Thermal ablation is one such treatment option in oncology for targeting primary and metastatic cancers unsuited for traditional surgical interventions.



NEEDLE BASED THERAPEUTIC ULTRASOUND (NBTU): Heating produced by the generated ultrasonic waves by the piezoelectric transducer can be used to directionally ablate a desired shape.

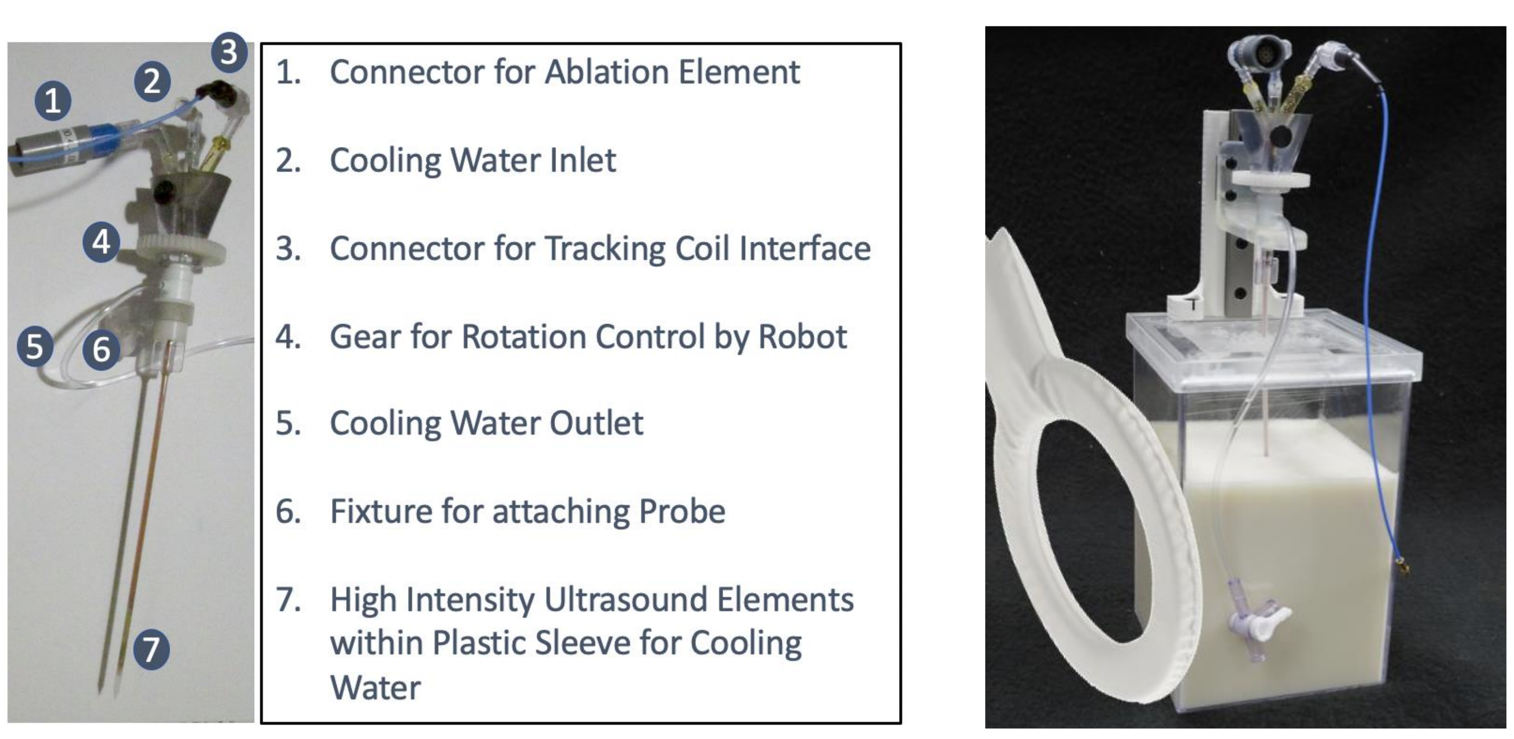


Figure 1. NBTU Probe with labeled details on left. Experimental setup of NBTU probe in phantom shown on right.

SIMULATION SETUP: A 3D Simulation of an NBTU transducer built using COMSOL 5.5 is presented. Since the beam pattern was known from our previous 2D models [2], a quarter region of the transducer and acoustic medium was simulated in order to simplify volume calculations.

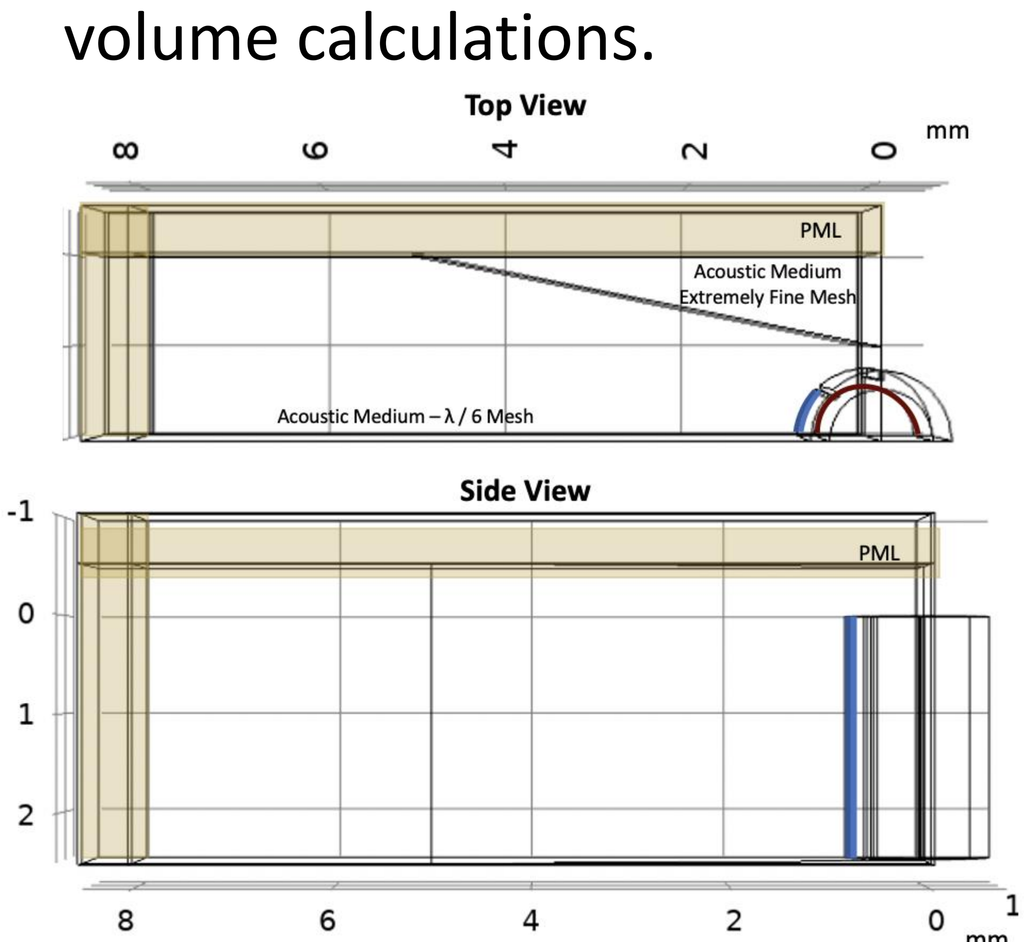


Figure 2. Simulation Geometry Setup

COMSOL Multi-Physics Interfaces

Solid Mechanics
- Piezoelectric Material
- Fixed Constraint

Electrostatics
- Applied to NBTU Probe
- 14V Applied to 90° Segment

Pressure Acoustics
- Applied to Medium
- Far Field PML

Bioheat Transfer
- User defined heat source
- Q = acpr.Q_pw * step(t – t_probeOn)

NBTU Properties	
Ceramic Material	PZT-4
Density	7500 (kg/m^3)
Resonant Frequency	5.2 MHz
Electric Potential	12V

Acoustic Medium Properties	
Heat Capacity	3451 (J/(kg*K))
Density	1058 (kg/m^3)
Thermal Conductivity	0.53 (W/(m*K))
Speed of Sound	1151 (m/s)
Attenuation	31.96 Np/m

STUDY RESULTS: Frequency sweep from 1 MHz to 10 MHz at 0.1 kHz increments was used to determine frequencies that induce transducer deformation. A resonant frequency of 5.0444 MHz was selected and used to compute an acoustic pressure field. A time domain study using these results was conducted to simulate ablation heating for 60 seconds.

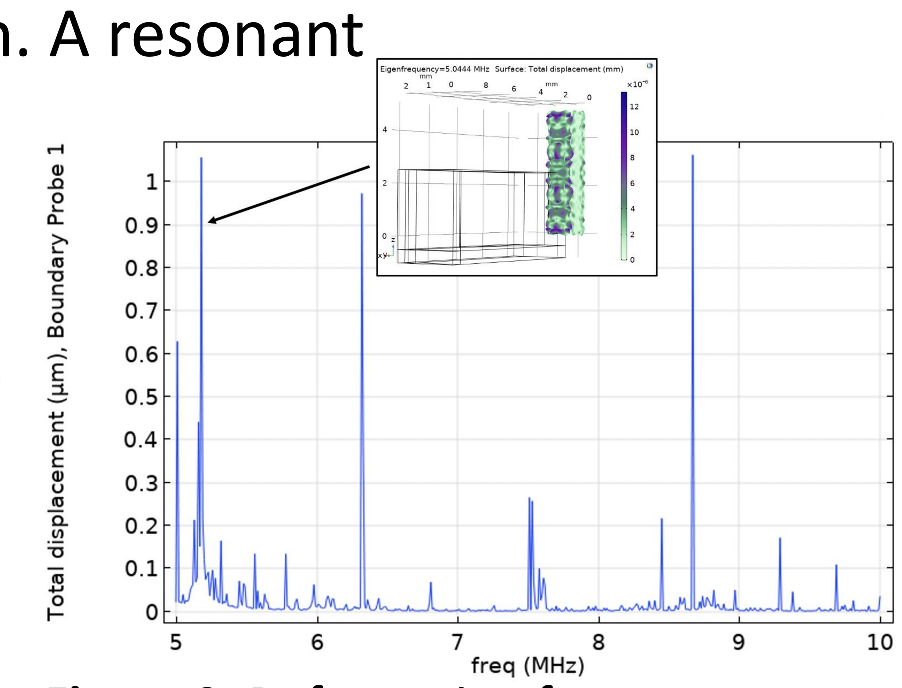


Figure 3. Deformation frequency sweep

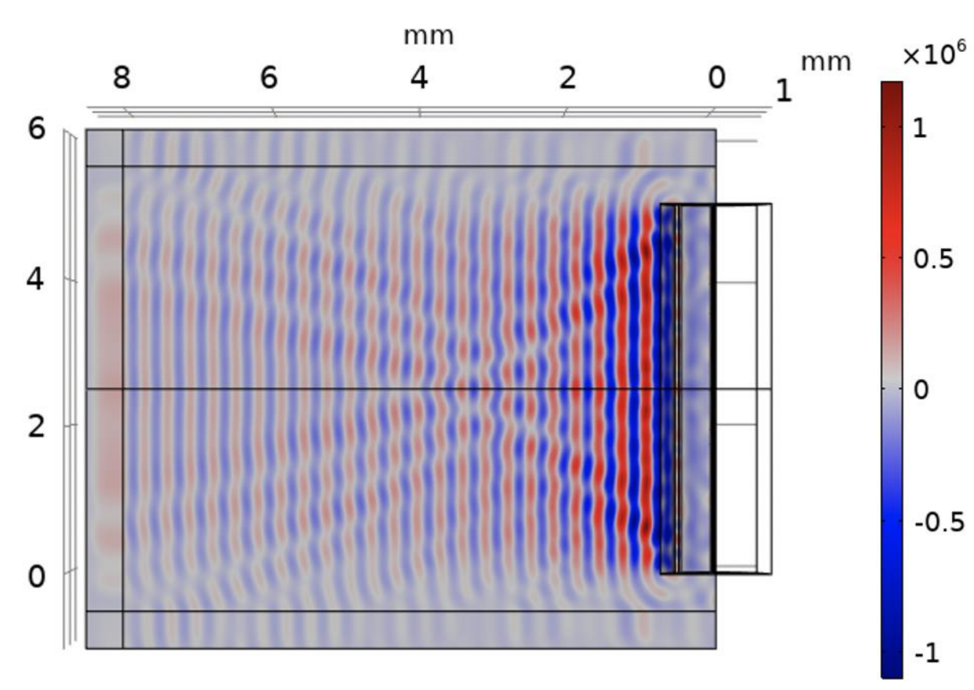


Figure 4. Side view acoustic pressure field

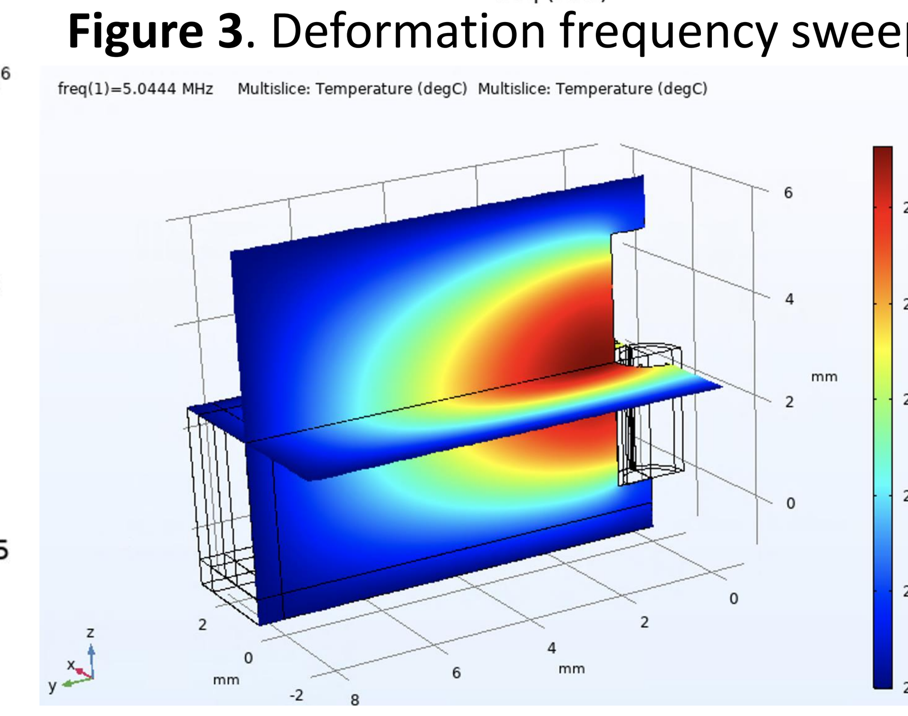


Figure 5. 3D view of bioheat transfer

EXPERIMENT AND RESULTS: Preliminary Experimental validation of the simulation was performed by collecting MR-Thermometry of the activated NBTU probe within a phantom of known acoustic properties [3]. Results for 60 second ablation are shown below.

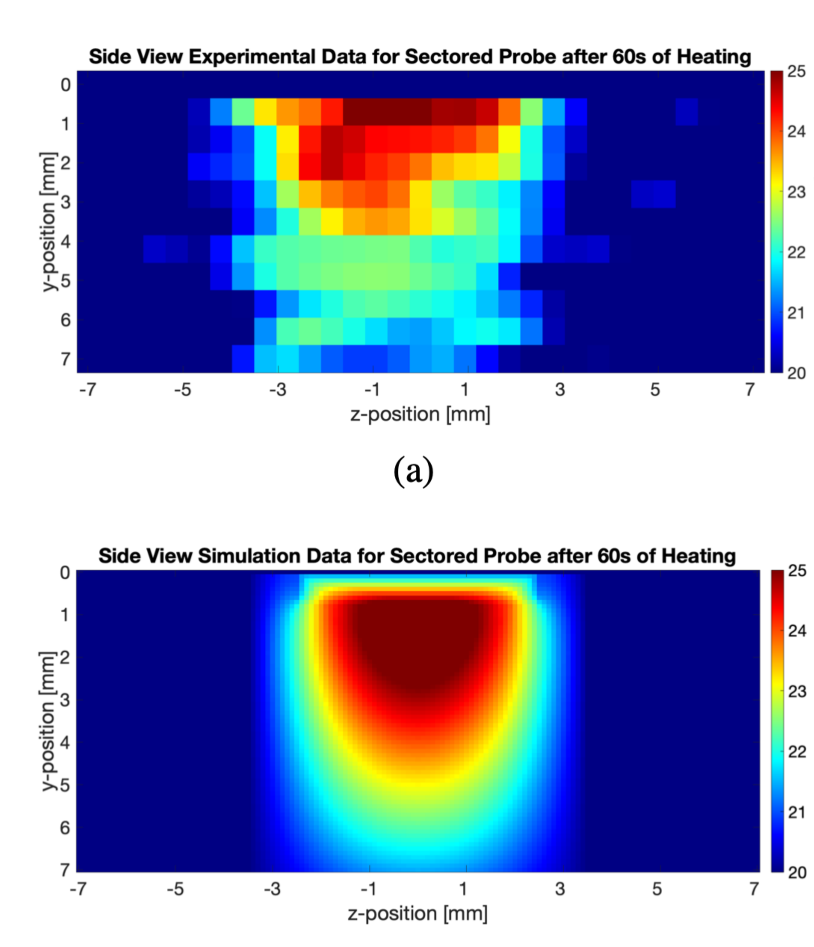


Figure 6. Side view comparison of the (a) Experimental and (b) Simulated Results

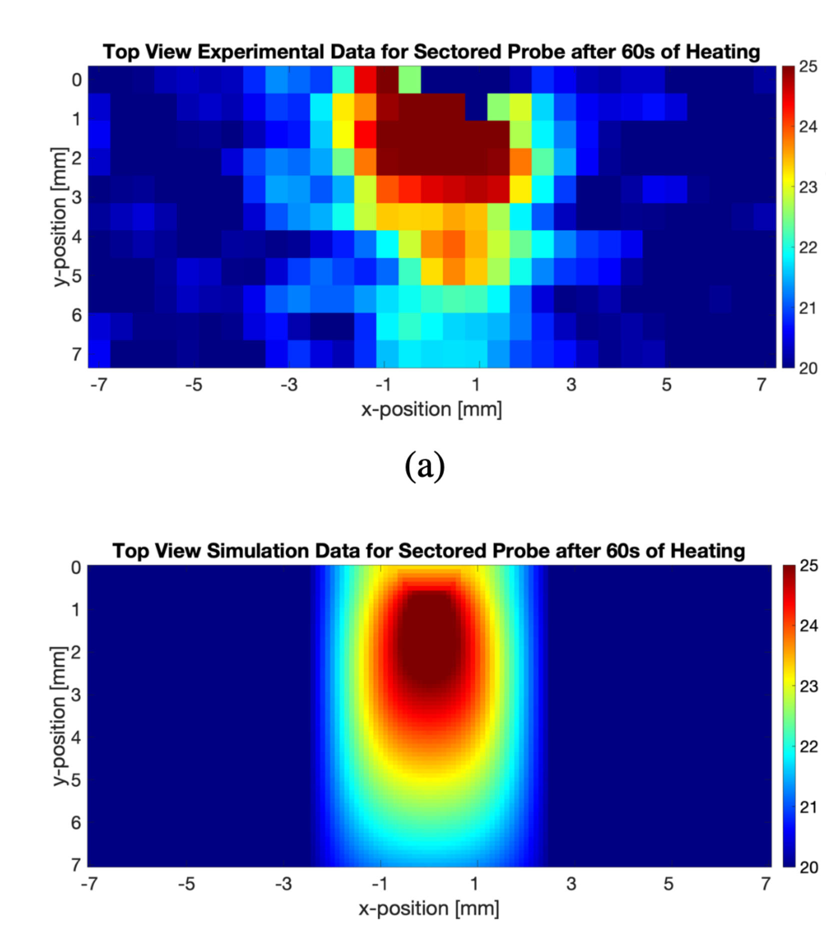


Figure 7. Top view comparison of the (a) Experimental and (b) Simulated Results

CONCLUSION: A Multiphysics simulation of a piezoelectric transducer for interstitial NBTU brain tumor ablation in 3D is presented. Future work:

- Further calibration of the simulated and experimental results
- Non-static material properties and blood perfusion

REFERENCES:

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