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Whole-Body Human Ultrasound Tomography

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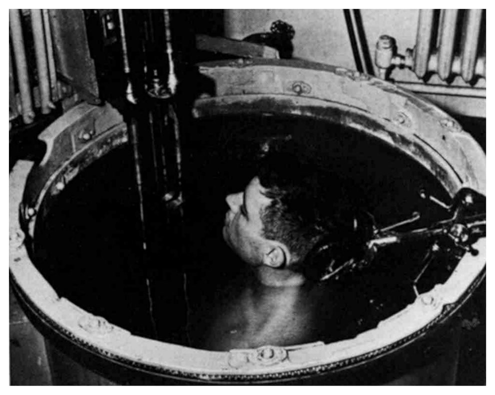
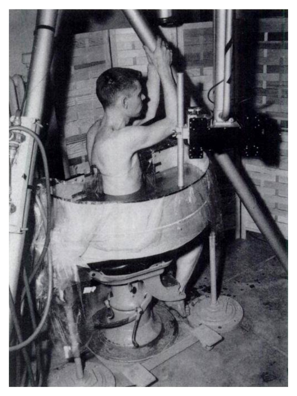
Background

Early ultrasound pioneers used single-element transducers and water immersion tanks which required long acquisition times [1]





Since then, we've been using ultrasonic probe arrays:

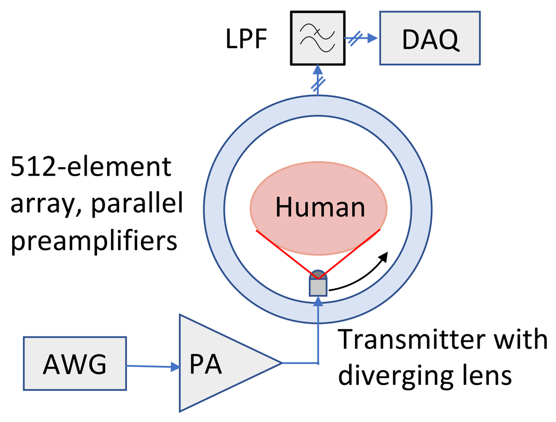
- Probes enable rapid anatomical and functional imaging
- BUT probes suffer from operator dependence, small field of view, difficulty visualizing behind bone or air, and single mode contrast

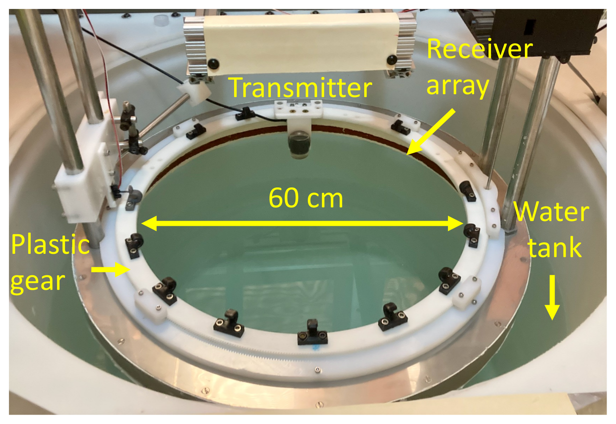
Ultrasound tomography of the breast or extremities [2] enables reflectivity, speed of sound, and attenuation coefficient in soft tissue

Can we extend ultrasound tomography to the whole human body?

Our System

- Water immersion tank with subject seated inside
- 512-element custom-built ultrasonic array (1 MHz, 60 cm diameter)
- Rotate single-element transmitter around subject
- ~10 s per 2D acquisition, move array up and down

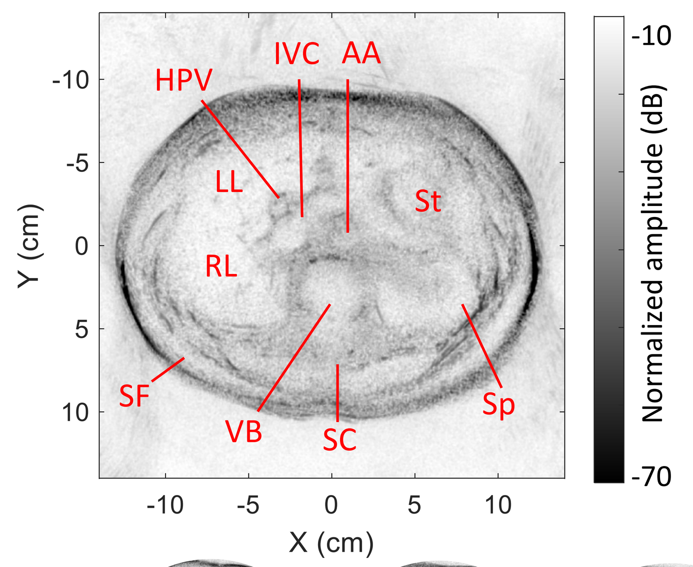




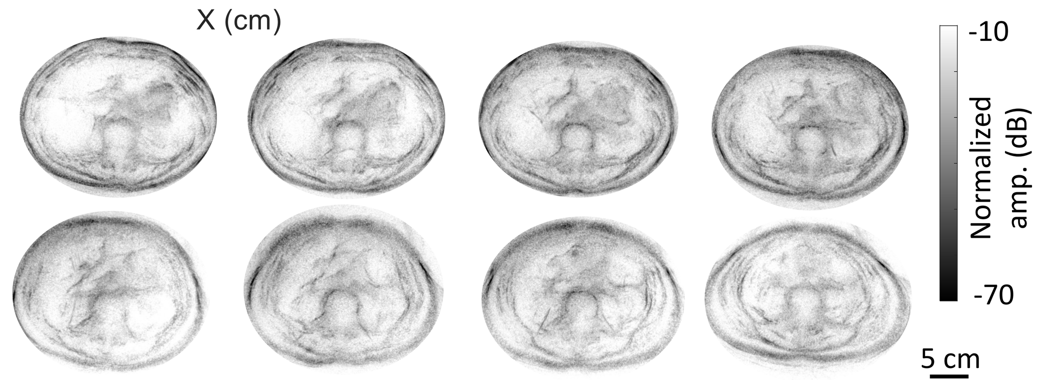
AWG: arbitrary waveform generator
PA: power amplifier

Results

2D cross-sections of the entire *in vivo* human abdomen [3]



IVC: inferior vena cava
AA: abdominal aorta
HPV: hepatic portal vein
St: stomach
RL: right lobe of liver
LL: left lobe of liver
SF: subcutaneous fat
Sp: spleen
VB: vertebral body
SC: spinal cord



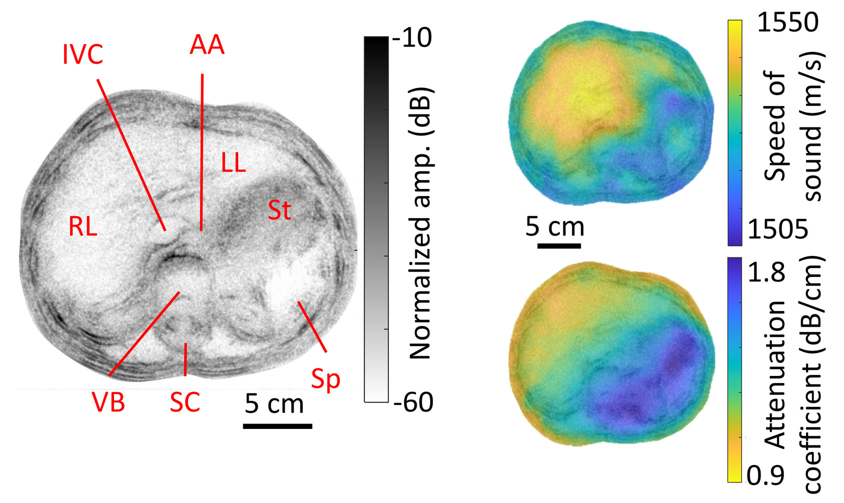
Whole-body ultrasound tomography of a healthy female subject.
Top: example slice showing several anatomical features.
Bottom: images obtained in 1 cm increments from the rib cage to the hip.
Each image was obtained in a 10 second acquisition

Applications

Tissue property estimation

Use signals transmitted through the body to obtain speed of sound and attenuation coefficient maps

- May be useful as indicators of tissue health (e.g., fatty liver)

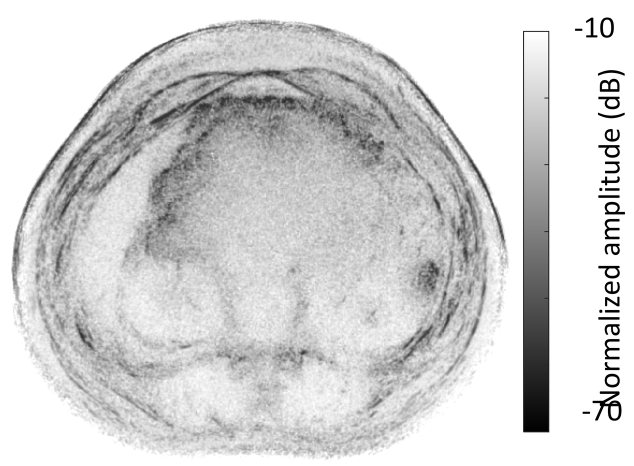


Ultrasound tomography of a healthy volunteer. Left: reflectivity image of human abdomen. Right: speed of sound and attenuation profiles, respectively, overlaid on the reflectivity image.

Subcutaneous fat thickness estimation

Extract fat thickness around the whole body

- Useful for pharmaceutical studies, alternative to fat calipers



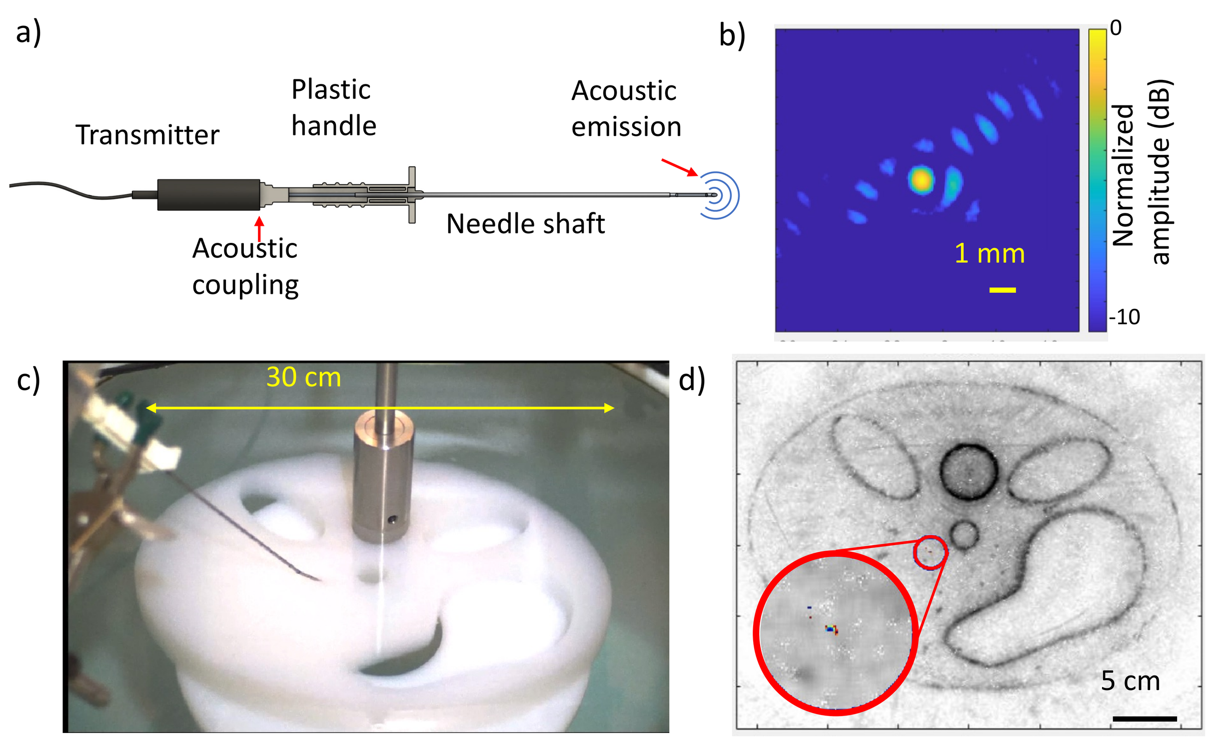
Whole-body ultrasound tomography of a healthy male subject. The subcutaneous fat thickness is observed around the periphery of the body

Biopsy needle localization

How to localize a biopsy needle with respect to internal anatomy?

- CT guidance biopsy: slow, radiation exposure
- Ultrasound probe: only superficial regions in soft tissue

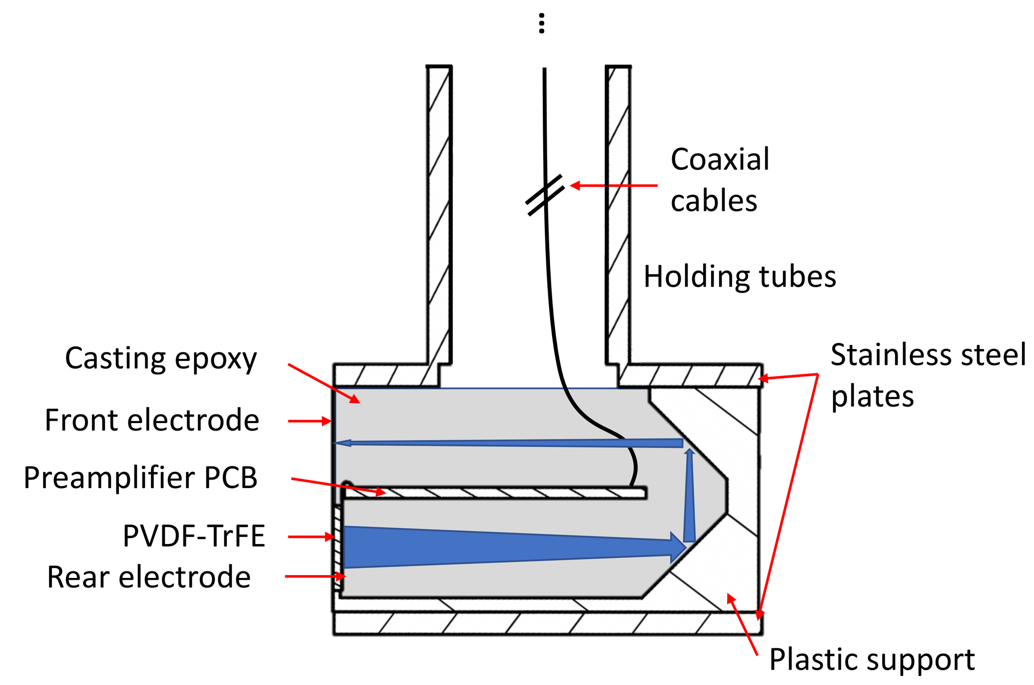
Couple ultrasound into needle, detect scattered signal with array
Overlay needle emission on reflection-mode image
Obtain ~7 fps video of needle location, < 1mm resolution over ~30 cm field of view



a) Diagram of needle configuration. b) Representative image of the needle's acoustic response in homogeneous water. c) Video frame showing the needle inserted into an agarose phantom. d) Reconstructed video frame overlaid on a reflectivity image. The red circle is automatically placed around the center acoustic response.

System Design

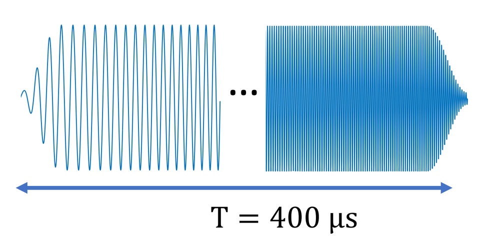
Custom-built array using PVDF-TrFE bonded to flexible electrodes
Connected to custom preamplifier array in a shielded enclosure



Main challenge: SNR!
Transmit chirp signal: T = 400 μs, B = 0.3 – 2.0 MHz
Boost SNR with limited peak negative pressure (mechanical index)
SNR enhancement ~ $\sqrt{T \times B} \sim 20$

Cross-correlate with water-only signals to recover pulse response

- Obtained from a scan without subject

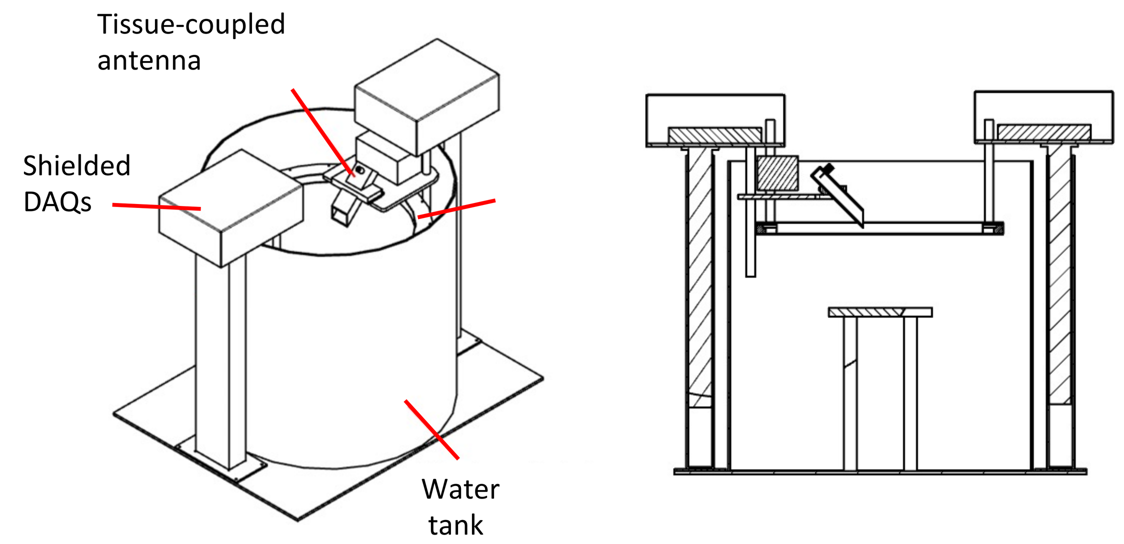


Outlook

Extend to 3D, higher ultrasound frequencies

Combine with photoacoustic and thermoacoustic tomography to obtain additional contrast mechanisms

- Optical/microwave contrast with acoustic resolution and depth



References

[1] J. H. Holmes and D. H. Howry, "Ultrasonic diagnosis of abdominal disease," Am. J. Dig. Dis., vol. 8, no. 1, pp. 12–32, Jan. 1963, doi: 10.1007/BF02233558.
[2] J. Wiskin, D. T. Borup, S. A. Johnson, and M. Berggren, "Non-linear inverse scattering: High resolution quantitative breast tissue tomography," J. Acoust. Soc. Am., vol. 131, no. 5, pp. 3802–3813, May 2012, doi: 10.1121/1.3699240.
[3] D.C. Garrett, J. Xu, Ku, G. Ku, & L. V. Wang, "Whole-Body Human Ultrasound Tomography," arXiv preprint arXiv:2307.00110, 2023.