Characterizing Tissue Stiffness Using Ultrasound Shear Wave Elastography

Alexa Garcia, Isaiah Smiley, Adnan Rayes, Qifa Zhou
Department of Biomedical Engineering, University of Southern California, Los Angeles, CA, USA
USC Viterbi School of Engineering

Background

Basic Imaging Device Components

Medical ultrasound is one of the main imaging modality that uses sound waves to produce images of soft tissue inside the body. These images are developed by using a transducer which send sound waves that bounces off tissues throughout the body. This creates an echo effect and reflects the signal back to the transducer which converts the mechanical waves into electrical signals. A computer is then used to process the electrical signals and create the image [1].

Compared to modern techniques and imaging modalities, ultrasound is one of the safest and efficient imaging systems because it relies on sound waves rather than more hazardous sources such as electromagnetic radiation. It also can be used in various situations such as diagnosing an illness or disease, evaluating blood flow, monitoring a baby's health during pregnancy, and treating medical conditions [2].

Recently, ultrasound has been used to characterize the mechanical properties of soft tissue through shear wave detection. Ultrafast images are taken while induce vibration to the sample to capture the displacement. This information is useful in ultrasound therapy, in which high-intensity focused ultrasound (HIFU) waves are used to dismantle tumors, kidney stones, and blood clots. Knowing the mechanical properties of the tissues being treated with HIFU ensures that the procedure remains safe and effective [3].

Study Aim

- Calculate tissue stiffness using ultrasound shear wave elastography
- Fabricate two phantoms with different stiffnesses and use elastography to characterize their stiffnesses
- Study the effect of tissue temperature on shear wave speed and therefore, the tissue stiffness
    - Accomplished using two different water temperatures

Methods

1. **Phantom Fabrication**
    a. Fabricated soft tissue-mimicking substances known as phantom
        i. Made with varying concentrations of distilled water, propanol, gelatin and silica
2. **Elastography Experiment**
    a. Generated Shear Wave
        i. Mechanical shaker rod was gently positioned on top of the phantom to cause tissue vibration
    b. Captured and track motion
        i. Ultrasound array probe aligned to rod
        ii. Images were taken Detected wave propagation along the phantom by a Verasonics system
    c. Calculated shear wave speed
        i. Data analysis performed with MATLAB to obtain a spatiotemporal map
        ii. Linear regression was applied to all negative peak displacement
        iii. The slope of these negative peaks were found and used to calculate shear wave speed

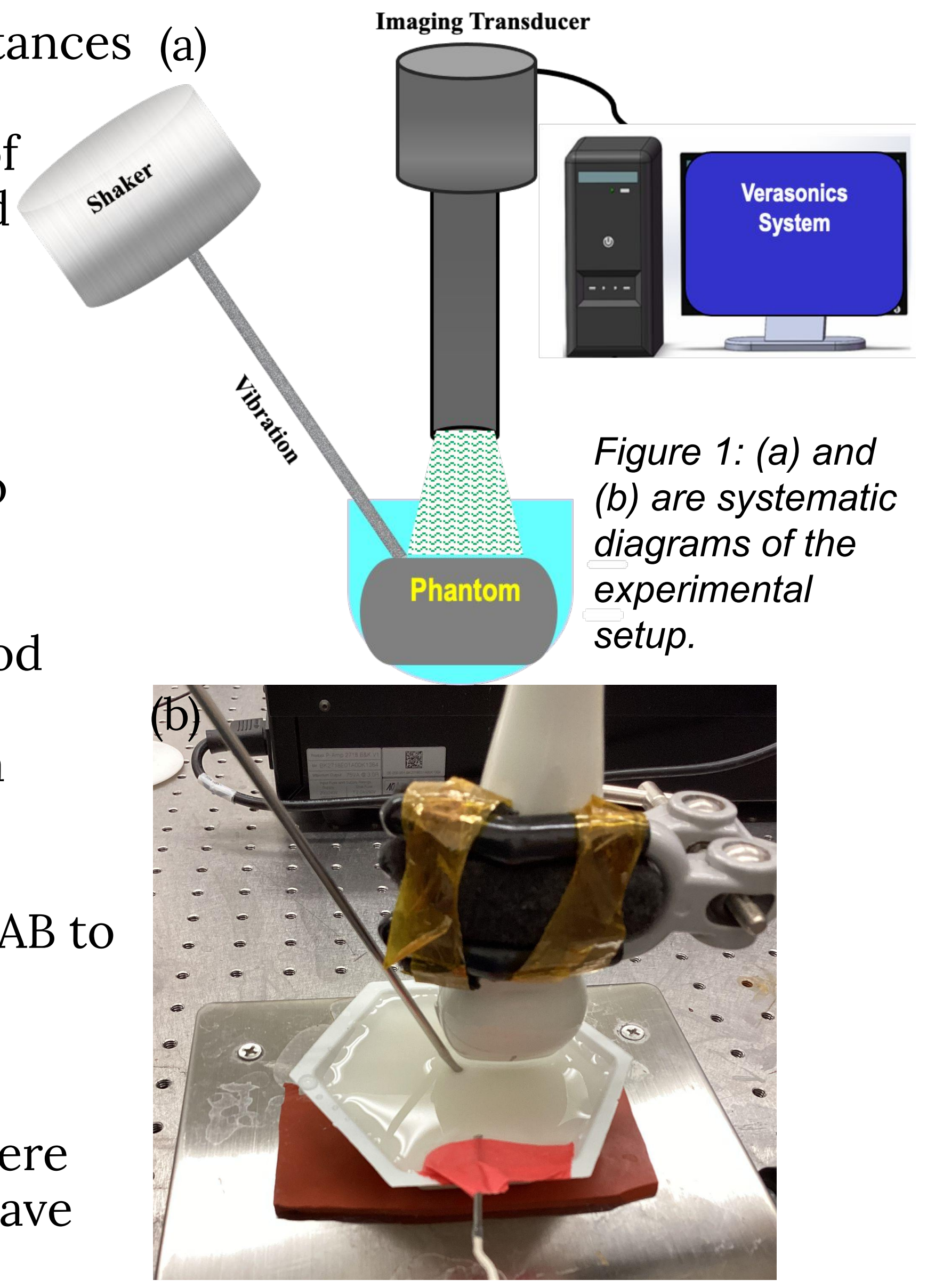

Figure 1: (a) and (b) are systematic diagrams of the experimental setup.

Results

Trial 1, 24 Hours After the Phantom Was Created

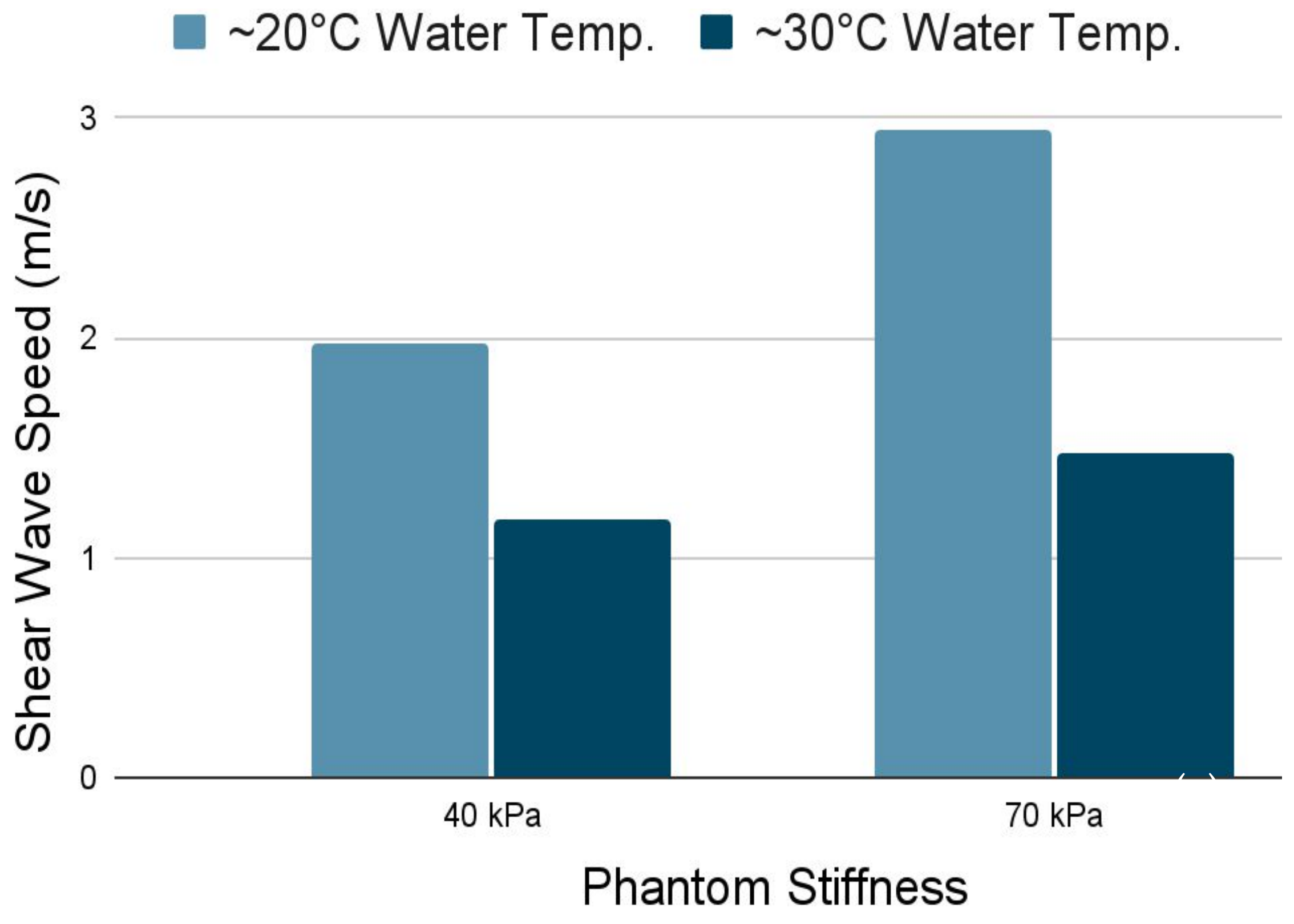

Table 1 (Trial 1)

Phantom Stiffness (kPa)	Water Temp. (° C)	Spatio-Temporal Slope	Shear Wave Speed (m/s)
40	18.7 ± 2	0.67	1.97
40	28.0 ± 2	0.40	1.18
70	20.0 ± 2	1.00	2.95
70	29.1 ± 2	0.50	1.47

Figure 2: Graphs (a) and (b) represent the relationship between phantom stiffness and shear wave speed.

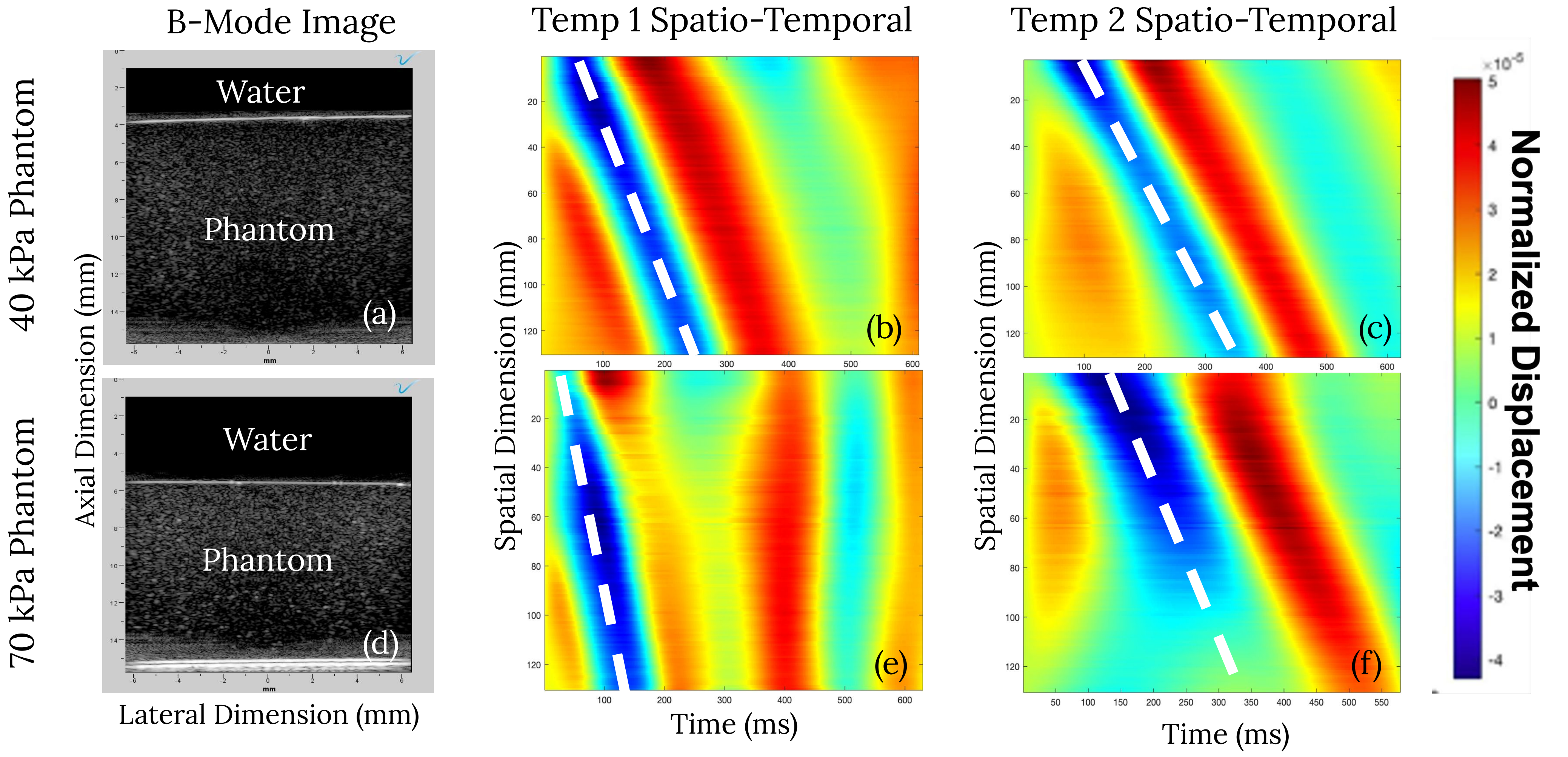

Figure 3: (a) and (d) are B-Mode images of the 40 kPa and 70 kPa phantoms, respectively. (b) (c) (e) and (f) are Spatio-Temporal maps of the two phantoms, with lower temperatures (b,e) and higher temperatures (c, f).

Trial 2, 48 Hours After the Phantom Was Created

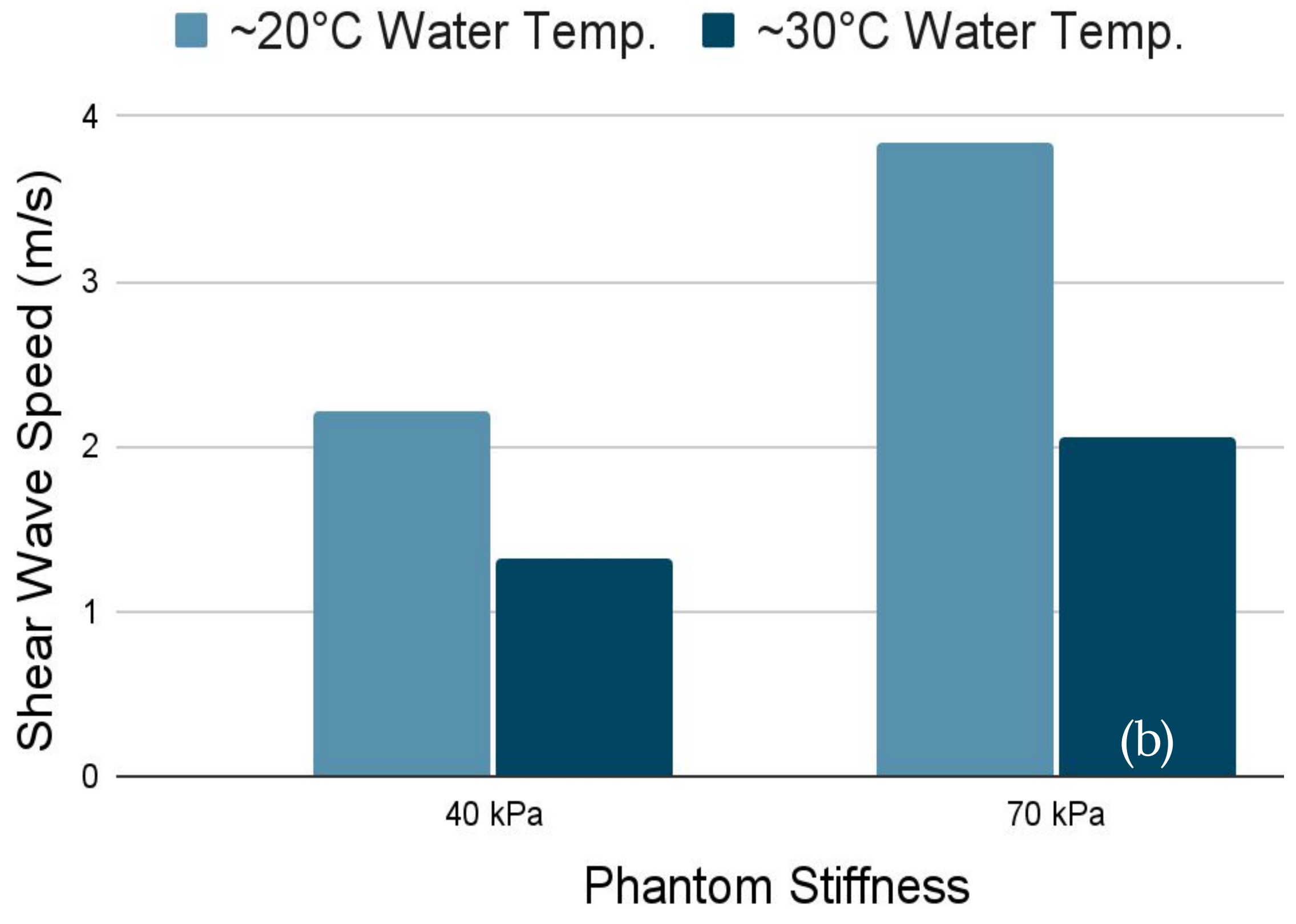

Table 2 (Trial 2)

Phantom Stiffness (kPa)	Water Temp. (° C)	Spatio-Temporal Slope	Shear Wave Speed (m/s)
40	17.9± 2	0.75	2.21
40	28.1 ± 2	0.45	1.32
70	18.0 ± 2	1.30	3.84
70	29.5 ± 2	0.70	2.06

Conclusion

Our results show that ultrasound shear wave elastography is a promising technique in characterizing the mechanical properties of soft tissue. There is a clear relationship between water temperature, and the shear wave speed. Our results suggest that tissue temperature has an inverse relationship with stiffness. With an increase of ~10°C, the phantom's shear wave speed decreased by about 50%. This remained consistent for both Phantoms stiffness (40 kPa and 70 kPa) samples in Trials 1 and 2.

Furthermore, we observed that the shear wave speed of the phantom increases as the phantom ages. In Trial 2 (tested 48 hours after the phantom was created) the shear wave speed of the 40 kPa phantom was 2.21 m/s, which is higher than Trial 1's 1.97 m/s. Each phantom's shear wave speed in Trial 2 was higher than the correlating speeds in Trial 1.

Future Work

Developing a better understanding of how the mechanical property of soft tissue is affected by temperature will allow professionals to diagnose and treat patients more effectively; the human body temperature is constantly changing. Thus, in our future work we will focus on expanding our experiment size to have more precise data. This includes using at least 4 different phantom temperatures and stiffnesses. In addition, we will confirm & validate the ultrasound performance at different water temperatures using the pulse-echo test.

References

[1] M. Makhsous et al., "Investigation of Soft-Tissue Stiffness Alteration in Denervated Human Tissue Using an Ultrasound Indentation System," The journal of spinal cord medicine, vol. 31, no. 1, pp. 88–96, 2008, doi: 10.1080/10790268.2008.11753987.

[2] Basic Principles of Ultrasound, https://www.dcconferences.com.au/lcmc2012/pdf/Phlebology_PrereadingFriday.pdf

[3] A. Rayes et al., "Estimating Thrombus Elasticity by Shear Wave Elastography to Evaluate Ultrasound Thrombolysis for Thrombus with Different Stiffness," IEEE transactions on biomedical engineering, vol. PP, pp. 1–9, 2022, doi: 10.1109/TBME.2022.3186586.