1P1-3

Temporal observation of shear wave propagation in biological tissue during liquid-solid phase change

Kento Shimizu[1†], Naoki Tano[1], Ren Koda[2], Yoshiki Yamakoshi[1,2], and Marie Tabaru[1*]
([1]IIR, Tokyo Tech; [2]Gunma Univ.)

1. Introduction

Recently, fascia hydrorelease has been attracting attention. During fascia hydrolysis operation, the tissue surrounding the fascia may change from solid to liquid phase. In addition, non-invasive lung diagnostics is important for emergency medicine. Pleural effusion may change from liquid to solid phase when lung becomes inflamed. Furthermore, the elastic characteristics of meat (e.g., quality of fat) or fruits[1)] is an important factor to evaluate their quality. In this study, we investigate the temporal observation of shear wave characteristics of tissue-mimicking phantom by phase changes in real time.

2. Experimental and simulation method

In this study, we used C-SWE (Continuous-Shear Wave Elastography) method developed by our group[2,3)]. Fig.1 shows the experimental setup. A vibrator and an ultrasonic probe were placed on a konjac phantom. 1 mL of melted beef tallow (fat) that had been warmed to 80°C was injected inside the konjac with a syringe, where the diameter of the syringe needle was 1 mm. Immediately after injection, measurements were taken for 10 minutes. The vibration frequency of continuous sine wave was set as 78.1 Hz. The waveform of shear wave was reconstructed from doppler signals by C-SWE technique[2,3)].

We also conducted velocity-stress FDTD (Finite-difference time-domain) method to model the experiment. The grid size and the time interval were 0.2 mm and 0.0125 ms, respectively. The calculation size was 100 and 40 mm in x and z directions, respectively. The vibration point was the origin. The fat was inserted at $z = 15$ mm as an oval with radii of 1 and 4 mm. Shear wave velocity of konjac was set to 3 m/s. Shear wave velocity, v, of fat was set to 0 m/s when the fat was liquid, and v of 1 and 2 m/s were used when the fat was solid.

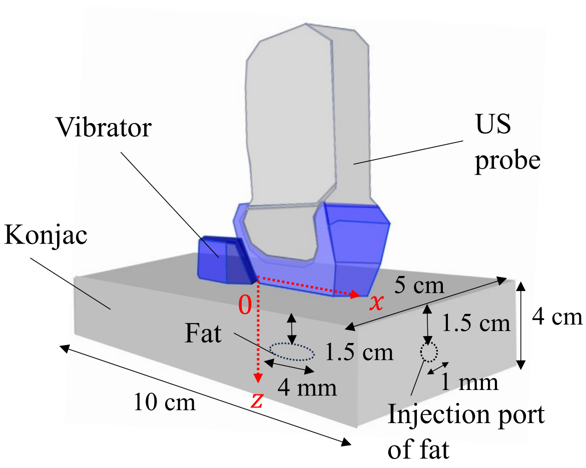

Fig. 1 Overview of experimental setup.

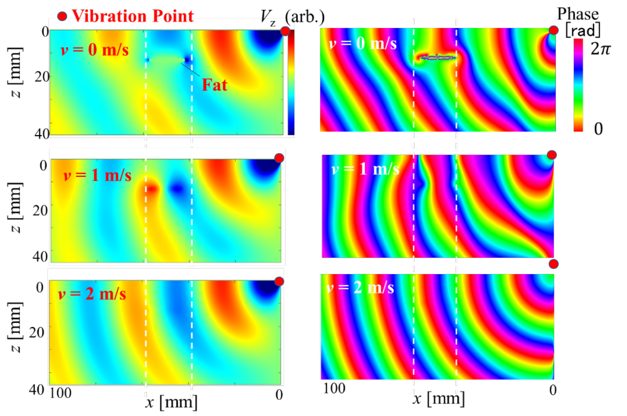

Fig. 2 Particle velocity v_z and reconstructed phase maps for difference velocity of beef tallow.

3. Results

Fig. 2 shows the FDTD simulation results of particle velocity and reconstructed shear wave phase maps by the C-SWE method for v = 0, 1, and 2 m/s. When v was 0 m/s, shear wave was reflected at the fat injection area resulted in phase shift. When v was 1 m/s, the reflection at the fat region decreased. The amount of phase shift also decreased, therefore, it becomes more difficult to confirm the fat area in the phase image compared in the case of v = 0 m/s. When v was 2 m/s, which was closer value to surrounding tissue, almost no reflection was occurred. In this case, fat area was not visible in the phase map.

Fig. 3 shows the experimental results of the change over time for the B-mode images, the reconstructed shear wave phase maps, and the reconstructed shear wave velocity maps. From the B-mode images in Fig. 3(a), no visible changes over time after the injection of beef tallow are observed. In the phase images in Fig. 3(b), the beef tallow

E-mail:†shimizu.k.bh@m.titech.ac.jp,
*tabaru.m.ab@m.titeh.ac.jp

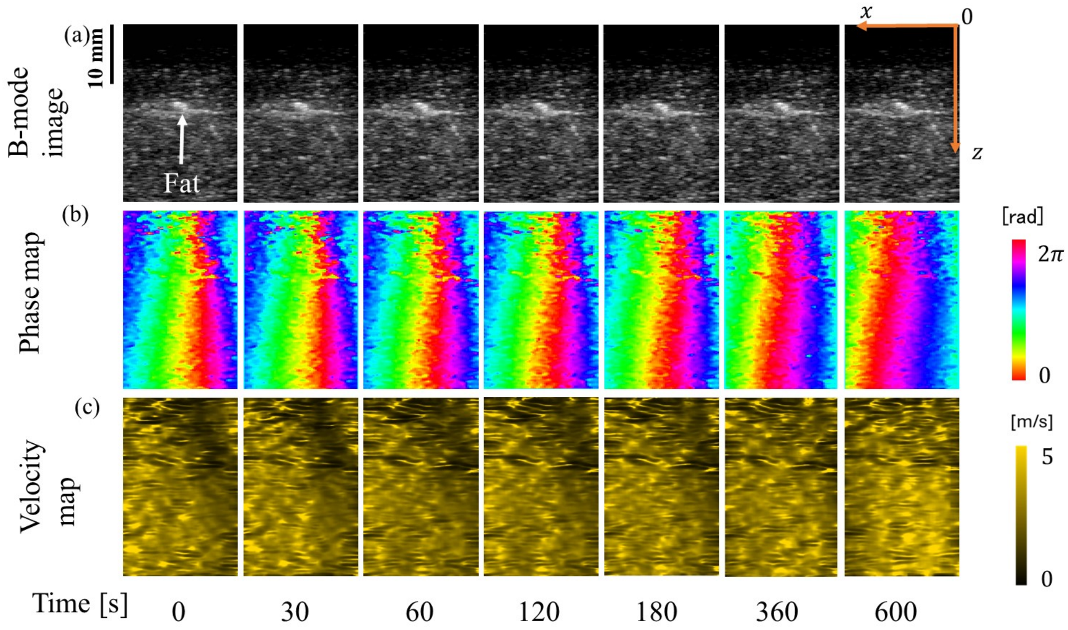

Fig. 3 Measurement results of C-SWE over time. (a) B-mode image, (b) shear wave phase map, and (c) shear wave velocity map.

injection area can be seen immediately after beef tallow injection at 0 s. As the time passes, the beef tallow-injected area gradually becomes unidentifiable on the phase map as it integrates with the konjac. The velocity maps in Fig. 3(c) shows that immediately after the injection of beef tallow, the velocity near the beef tallow-injected position is low. On the other hand, as time passes, the velocity in the beef tallow-injected area increases. We considered that this was due to the increase of the elastic modulus of the beef tallow as the time passed, which changed the shear waves propagation characteristics.

A velocity distribution in the x direction at z = 11.5 mm, i.e., around injected position of the beef tallow, is shown in Fig. 4. The area of the beef tallow is at x = 6 - 10 mm. The amplitude of velocity around the injection area is small immediately after the injection of beef tallow. As the time passes, the velocities in the beef tallow area tend to increase, indicating that the beef tallow becomes hardened.

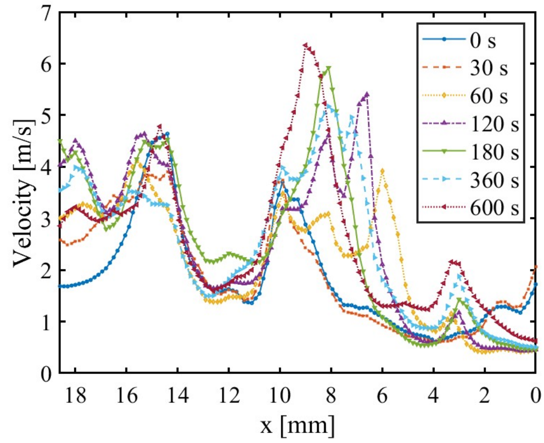

Fig. 4 Experimental results of velocity changes in *x*-direction at *z* = 11.5 mm.

4. Conclusion

From the study, the phase and velocity changes of shear waves were confirmed during the liquid-solid phase change. Simulation results showed that when the speed of the fat became closer to that of the surrounding area, it became less visible of fat in the phase map. In the experiment, the shear wave phase change of beef tallow was observed in real time. In addition, gradual increase in velocity was observed, confirming the hardening of beef tallow. A future work is to theoretically analyze solid-liquid phase change.

Acknowledgement

This work was supported by JSPS KAKENHI Grant Number JP22K04134, the Cooperative Research Project of Research Center for Biomedical Engineering, and JKA's promotion funds from KEIRIN RACE.

References

1) Tabaru M., Wu C, Murata K., Aoyagi T., and Nakamura K., Jpn. J. Appl. Phys. **63**, 086501 (2024).
2) Yamakoshi Y., Sato J., Sato T., IEEE Trans Ultrason Ferroelectr Freq Control, **37**, 45– 53 (1990).
3) Tabaru M., Koda R., Shitara H., Chikuda H., and Yamakoshi Y., Journal of Medical Ultrasonics, **51**, 407-418 (2024).