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Shear wave elasticity imaging for tissue engineering: probing superficial regions

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1. Introduction

Tissue engineering aims to improve or replace the structure and function of deteriorated tissue using various biomaterials. In tissue engineering, the mechanical property of biomaterials is one of the most important factors because it can significantly affect the biocompatibility, biodegradability, cell behaviors and functions. In order to measure these mechanical properties non-invasively and non-destructively, shear wave elasticity imaging (SWEI) have been attempted for tissue engineering applications[1]. However, SWEI can easily suffer from reverberations because numerous tissue engineering therapeutics are applied in superficial regions where multiple reflections can occur due to a large difference in acoustic impedances of bone and soft tissue[1,2]. In this study, to investigate the effect of reverberations in the superficial regions, shear modulus was quantified in gelatin phantoms with a thickness of 9 mm and 70 mm. Also, SWEI was performed according to the various angles of incidence and the distances between the transducer and the phantom surface to reduce quantification errors due to reverberations in the superficial regions.

2. Materials and methods

1.1 Tissue-mimicking phantom fabrication

Gelatin (Sigma Co., St. Louis, USA) and psyllium hydrophilic mucilloid fibers (sugar-free Metamucil®) were used to fabricate tissue-mimicking phantoms. 2% psyllium hydrophilic mucilloid fibers were added to 6% gelatin to create speckle patterns in ultrasound images[3]. To compare the effects of reverberations in the superficial regions, two phantoms with different heights of 70 mm (10 × 10 × 7 cm^3) and 9 mm (10 × 10 × 0.9 cm^3) were fabricated.

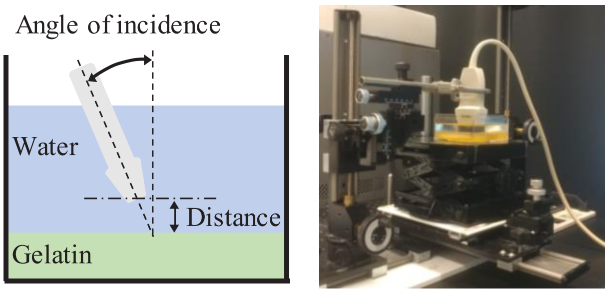

Fig. 1 Description of the angle of incidence and distance between the transducer and the phantom surface (left) and the experimental setup of SWEI (right).

1.2 Shear wave elasticity imaging

The ultrafast ultrasound imaging was performed in programmable ultrasound data acquisition system (Vantage 128, Verasonics Inc., Kirkland, WA, USA) using a linear array transducer (L7-4, Philips Healthcare, Andover, MA, USA). The tissue-mimicking phantoms were used in ultrafast ultrasound imaging at each angle of incidence and distance between the transducer and the phantom surface as shown in **Fig. 1**. Pushing was performed at a depth of 4 mm below the surface of the phantom during 500 μs using 16 elements with a center frequency of 4 MHz. Moreover, receiving was performed 100 times with a pulse repetition interval of 100 μs using 128 elements at a center frequency of 6.5 MHz. The acquired ultrasound B-mode data at various time points were processed through 2D autocorrelation of axial particle velocities and cross-correlation of shear wave velocities. Also, shear moduli in the region of interest (ROI) around the pushed area shown in **Fig. 2** were calculated.

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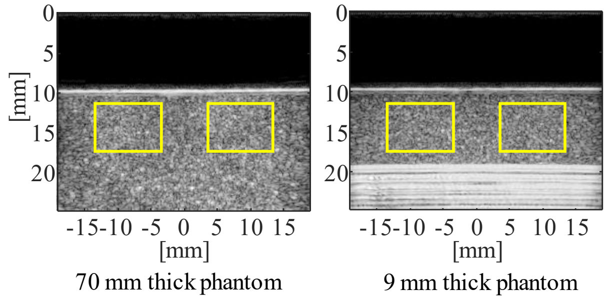

Fig. 2 B-mode images and ROIs of 9 mm and 70 mm thick phantoms.

3. Results and discussion

The SWEI was performed by pushing the phantom at a depth of 4 mm below the surface of the phantom during 500 us and by acquisition of 100 frames. To investigate the effect of reverberation, mean of shear modulus and its standard deviation of deep (70 mm) and shallow (9 mm) phantoms were measured and compared considering the effects of the distance between the transducer and the phantom surface as shown in **Fig. 3**. The assessment of shear moduli of the 9 mm thick phantom was more fluctuated with larger standard deviations than that of the 70 mm thick phantom possibly caused by reverberation. **Fig. 4** presents the shear moduli measured by SWEI with various angles of incidence (0 °, 2 °, 4 °, 6 °, 8 °, and 10 °) and distances between the transducer and the phantom surface (0 mm, 5 mm, 10 mm, and 15 mm). In addition, it was confirmed that the results of SWEI were more consistent with a distance of 5 mm and 10 mm compare to those of 0 mm and 15 mm. It can be caused by low efficiency of excitation owing to near-field effects or significant acoustic attenuation. The effects of the incident angles were also shown in **Fig. 4**. Specifically, it was observed that the measurement of shear moduli with appropriate distances (5 mm and 10 mm) was more accurate and less fluctuated at 2 ° and 4 ° than other angles by reduction of reverberation effects and reflection loss. Especially, in the case of the incident angle of 10 ° at 10 mm and 15 mm depth, the ultrasonic waves were significantly reflected so that the shear modulus cannot be accurately measured.

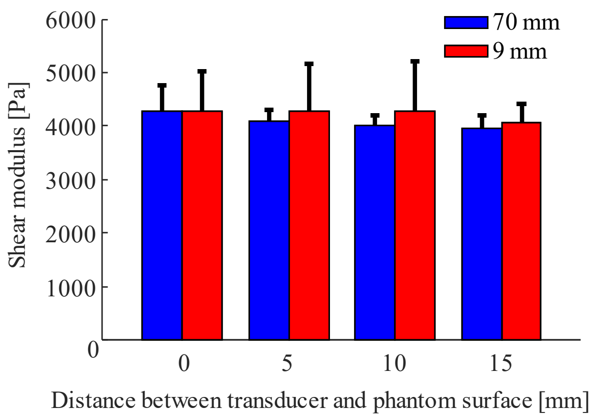

Fig. 3 The means and standard deviations of the shear moduli according to the distances between the ultrasound transducer and the surface of 9 mm and 70 mm thick phantoms.

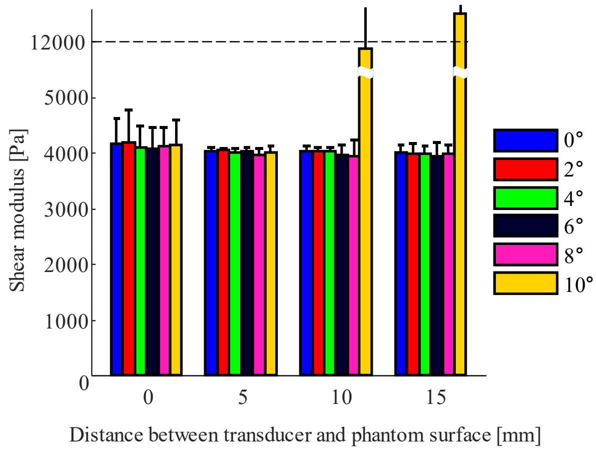

Fig. 4 The means and standard deviations of the shear moduli at ROI with various angles and distances between the ultrasonic transducer and the surface of the 9 mm thick phantom.

4. Conclusions

In conclusion, it was demonstrated that reverberation effects can produce errors in SWEI when it is used in a superficial region. To reduce the errors, the angle of incidence as well as the distance between the transducer and the phantom surface need to be appropriately designed. The study can be further extended to various tissue engineering applications with *ex vivo* and *in vivo* models.

Acknowledgment

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