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# FDTD verification of influence of layered structure on shear wave velocity

FDTD 法を用いた層構造がせん断波速度評価に与える影響の検証

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## 1. Introduction

Shear wave elastography (SWE) is a diagnostic method that non-invasively measures the stiffness of living tissues, and is considered to be an index for lesion detection and specific diagnosis. In recent years, it has begun to be applied to muscles, but it has been suggested that the evaluation accuracy of shear wave velocity (SWV) differs depending on the positional relationship between the propagation direction and the running direction of the muscles. In addition, there is a possibility that the acoustic radiation force (ARF) may not be input as expected in a tissue with strong anisotropy [1].

In this study, we conducted computer simulations of shear wave propagation in a medium with layered structure under actual ARF transmission conditions, and investigated the effect of the layer structure on SWV evaluation.

## 2. Reproduction and evaluation of shear wave propagation

### 2.1 FDTD simulation

**Figure 1** shows the schematic image of a simulation space. The shear wave propagating in the lateral direction was simulated using the elastic finite-difference time domain (FDTD) method [2] by adding the ARF to the center of the simulation space.

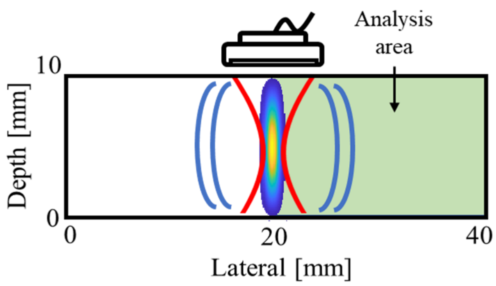


Fig. 1 Schematic image of simulation

Only the right half region of the simulation space was used for the analysis of shear wave propagation.

The ARF was mimicked acoustic field of push pulse of abdominal linear array probe (9L-D, GE Healthcare) of a clinical ultrasonic diagnostic equipment (LOGIQ S8, GE Healthcare). The left column of **Fig. 2** shows a homogeneous model, two-layers model, and three-layers model (10 mm × 40 mm; 1 pixel = 100 µm). The shear wave was calculated from the particle velocity for the depth direction. In each layer model, the SWVs of the basic region and a high speed region (5 mm × 40 mm) were settled to 2 m/s and 4 m/s, respectively. The simulation calculation time was 12 ms, and the time grid was determined to 0.47 µs considering the Courant condition. The perfectly matched layer (PML) method proposed by Berenger is used to eliminate unwanted reflections from the edges of the simulation space.

### 2.2 SWV evaluation

The propagation time difference $\tau$ of the shear wave was calculated by the cross-correlation method in the time waveform of two points on the spatial grid adjacent to each other in the lateral direction. At the time of calculation, a Tukey window with twice the wavelength was applied. The cross-correlation function $R(\tau)$ was calculated as

$$R(\tau) = \int v_1(t) \cdot v_2(t + \tau)\, dt \qquad (1)$$

where the $v_1$ and $v_2$ are the time waveforms of the particle velocities in the depth direction at two consecutive points in the lateral direction, respectively. The shear wave propagation time difference $\tau$ is the time when $R(\tau)$ is maximum.

The SWV was calculated as

$$\mathrm{SWV}(x, y) = \frac{\Delta x}{\tau} \qquad (2)$$

where the propagation time difference $\tau$ and the distance $\Delta x$ between the spatial grids between two adjacent points. The SWVMAP in the analysis area was created by calculating in each spatial grid [3].

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## 3. Results

The center column and the right column of **Fig. 2** show the particle velocity maps of depth direction 2.5 ms after the ARF was added and the SWVMAPs, of each simulation model, respectively. **Figure 3** shows boxplots of SWV in the basic region (Basic) and high speed region (High speed) in each model.

In the homogeneous model (**Fig.2 (a)**), the propagation of shear waves is stable, although there is slight dispersion depending on the evaluation position as shown in **Fig. 3(a)**. In the two-layer model (**Figs. 2 (b) and 3(b)**), the shear wave propagates fast and straight in the lateral direction in the region where the SWV is fast (4 m / s), however, propagates diagonally in the basic region (2 m / s). It is also confirmed that the spatial SWV variation is large. These features are also confirmed in the 3-layer model (**Figs. 2 (c) and 3(c)**). This is because the propagation direction of the shear wave changes with elapsed time due to the difference in sound velocity between regions, and deviates from the theory evaluated only in the horizontal direction by Eq. (2). Furthermore, the influence of the artifacts that occur at the boundaries is also large. The smaller the basic region compared to the high-speed region, the stronger these tendencies were shown.

## 4. Conclusions

As the results of the shear wave propagating simulations in layer models by the elastic FDTD method, the SWV evaluation results were varied from the theoretical values depending on the influence of the boundary and the difference in sound velocity of each layer. The evaluated SWV was significantly different from the default sound velocity in the case of the three-layer model. In other words, it was suggested that the accurate evaluation of the SWV by the general method is difficult in layered tissue such as muscles.

In future works, detailed studies will be conducted using simulation models that reproduces the fiber structure of muscles and bones. The relationship between the SWV calculation protocol and the evaluation accuracy for complex tissues will also be examined.

**Acknowledgment**
This work was partly supported by JSPS Core-to-Core Program, JPJSCCA2017000, the Institute for Global Prominent Research at Chiba University.

**References**
1. Palmeri M.L., el al; *IEEE TUFFC*, **64** (2017)
2. Sato. M, *Introduction to analysis of elastic vibration and wave motion by FDTD method, Morishita Publishing* (2003) [in Japanese]
3. Yamakawa M, *Med. Image. Tech.*, **32** (2014)

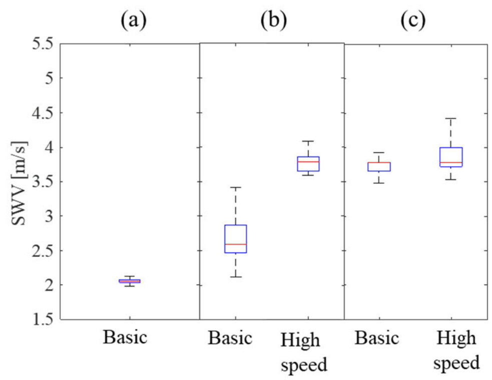


Fig. 3 Boxplots of SWVs of homogeneous model (a), two-layers model (b), and three- layers model (c).

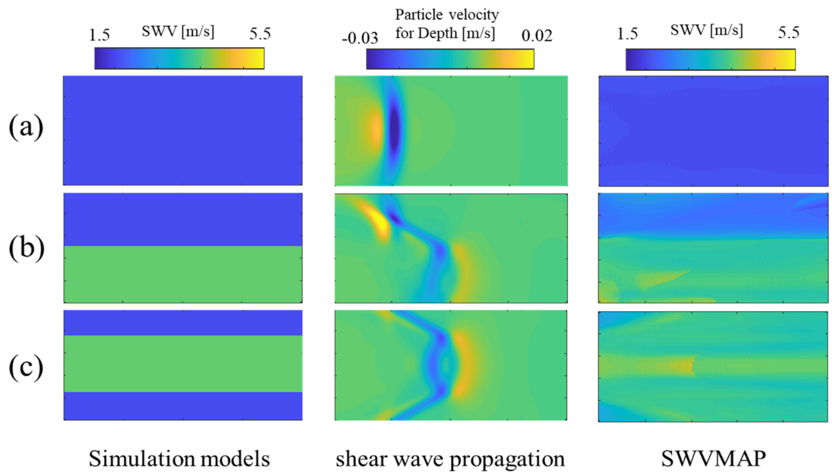


Fig. 2 Simulation models, shear wave propagation maps, and SWVMAPs of homogeneous model (a), two-layers model (b), and three-layers model (c).