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Evaluation of accuracy in ultrasonic measurement of motion velocity with simulation of blood vessel deformation

血管変形モデルシミュレーションを用いた超音波による速度計測の精度評価

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1. Introduction

Atherosclerosis is one of the important factors of myocardial infarction. Ultrasound diagnosis is widely used to detect the presence of atherosclerosis. In this diagnosis, however, morphological information is mainly utilized, and the diagnoses of plaque stiffness and vulnerability are difficult. Therefore, the evaluation in the elastic properties of the vessel wall is demanded in such a situation.

In the present study, the accuracy of the ultrasonic dynamic measurement method was evaluated by performing simulation experiments. The simulation of vessel deformation including fluid-structure interaction was performed using the COMSOL Multiphysics software. Then, the ultrasound simulation was performed using the obtained results. We compared the motion velocity of the vessel wall estimated using the simulated ultrasonic signals with the true velocity and calculated the bias error and standard deviation.

2. Materials and Methods

A model of a carotid artery was assumed to be a homogeneous, isotropic, Hooke's solid, incompressible, and circular tube. Its inner and outer diameters were 8 and 10 mm, respectively. Also, the thickness of the tube was set at 1 mm. The tube was enclosed with a tissue-mimicking material whose diameter was 30 mm. The length of the tube was 100 mm. An ellipsoid area, which corresponded to plaque, was placed at the luminal surface of the vessel wall and occupied one-third of the lumen. **Figure 1** shows the model used for the analysis.

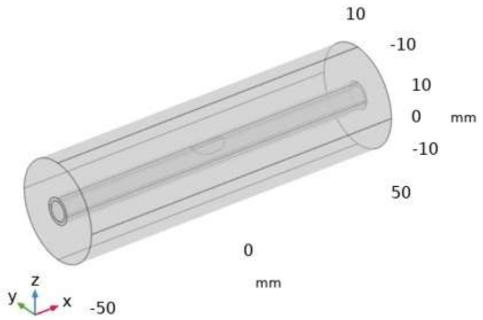

Fig. 1 Model for COMSOL Multiphysics.

The fluid is assumed to be incompressible, and the governing equations are the continuity equation and Navier-Stokes equation. The density and viscosity of the fluid simulating blood were set to 1060 [kg/m^3] and 0.005 [Pa· s], respectively. The boundary conditions for the inlet velocity v (unit: m/s) and outlet pressure p (unit: mmHg) are given by

$$v(t) = 0.6\sin(\pi t) \quad [\mathrm{m/s}],$$
$$p(t) = 5\sin(\pi t) \quad [\mathrm{mmHg}],$$

where t denotes time and the time-step was set at 0.025 s. The mechanical properties of the model, i.e., Young's modulus of the vessel wall E_w, Young's modulus of plaque E_p, Young's modulus of tissue E_t, density ρ, and Poisson's ratio ν, are shown in **Table I** [1]. Density and Poisson's ratio of the vessel wall, plaque, and tissue are the same.

Table I Mechanical properties of the model.

Mechanical Parameters	**Values**
E_w	600 kPa
E_p	100 kPa
E_t	200 kPa
ρ	1.024 kg/m^3
ν	0.49

Field II was used for ultrasonic simulation [2,3]. Echoes were received by a linear array probe with a center frequency of 7.5 MHz at a sampling frequency of 31.25 MHz. The number of elements was 192 in the lateral direction with a pitch interval of 0.2 mm. One B-mode image was reconstructed from the received signals with one plane wave transmission. Point scatterers were randomly distributed in the model shown in Fig. 1. The displacements at the scatterers were obtained by interpolating the displacements obtained by the simulation with the COMSOL software. The scattering intensities in the vessel wall, plaque, and tissue were set at 15, 10, and 5, respectively.

The 2D phase-sensitive method was used as a

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displacement estimator [4]. **Figure 2** shows a B-mode image of the simulation phantom. The red area shown in Fig. 1 was the tracking area for the estimation of the axial velocity. The size of the correlation window was set at ±2 mm (lateral) × ±0.4928 mm (axial).

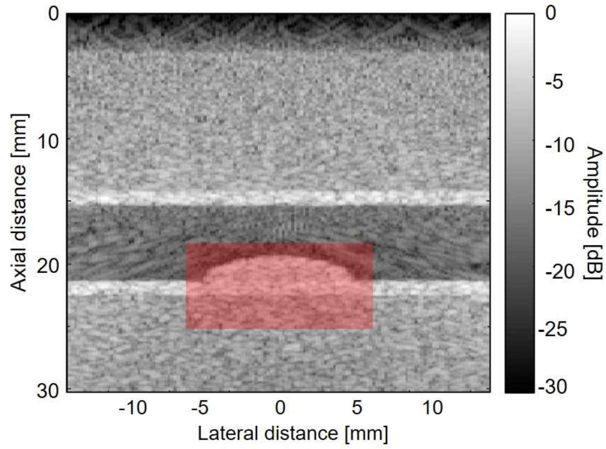

Fig. 2 Region of interest in B-mode image.

3. Results

In the simulation, an example on the axial velocity distribution in the plaque and posterior wall estimated by the 2D phase-sensitive method is shown in **Fig. 3**. **Figure 4** shows the distribution of the true values in this vessel deformation simulation.

Figure 5 shows the bias errors and standard deviations (SDs) in the estimated axial velocity by comparing with the true value from 0.2 to 0.8 s. As the true velocities during 0.0-0.2 s and 0.8-1.0 were almost 0 mm/s, the corresponding results were ignored in this evaluation.

The bias error and SD were -4.52 ± 6.80% at a time of 0.2 s. The results shown in Fig. 5 show that the velocities were underestimated compared to the true values.

4. Conclusion

The accuracy of the 2D phase-sensitive motion estimator was evaluated by performing the simulation phantom experiments.

In the future study, the accuracy in estimation of the axial strain will be evaluated based on the simulation data.

References

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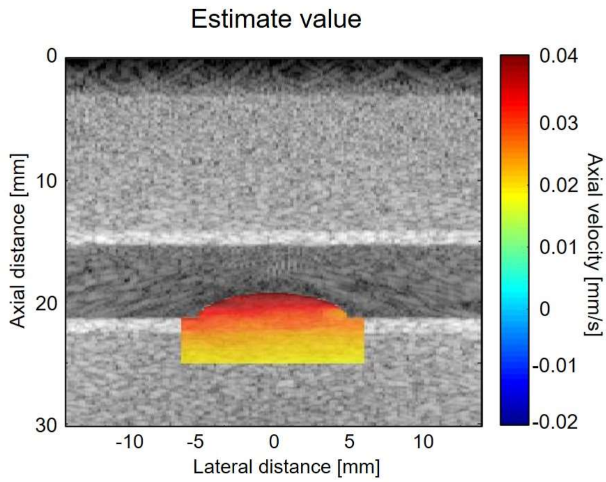

Fig. 3 B-mode image of the simulation phantom and the axial velocity distribution using the 2D phase-sensitive method.

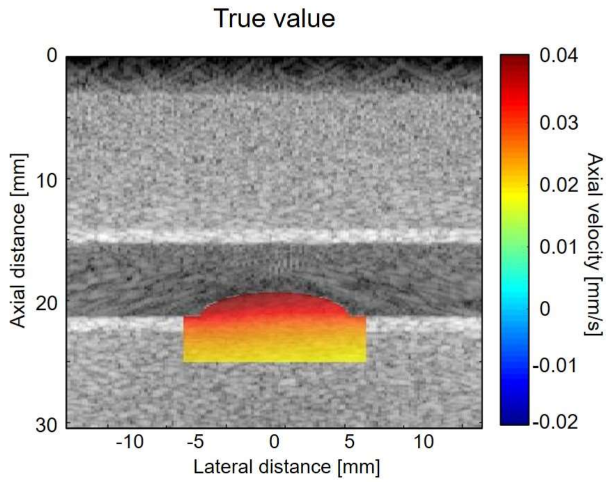

Fig. 4 B-mode image of the simulation phantom and the axial velocity distribution obtained by vessel deformation simulation.

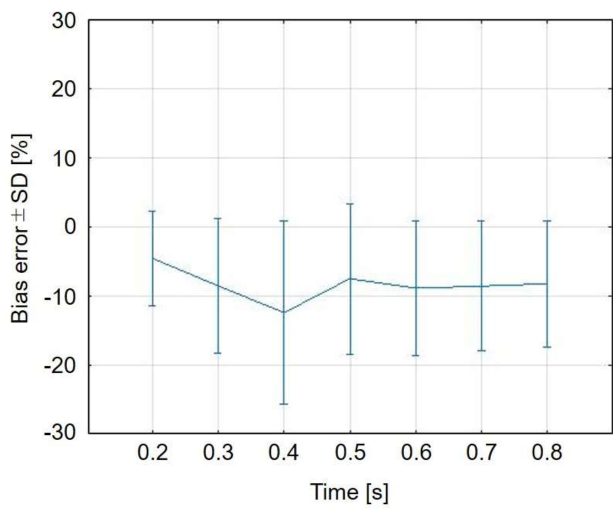

Fig. 5 Bias error and SD of the axial velocity compared to the true and estimated values.