3Pa5-2

# Effect of skull bone shape on Transcranial Doppler measurements

## 頭蓋骨形状が TCD 法に与える影響


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### 1. Introduction

The Transcranial Doppler method (TCD) enables the measurement of cerebral blood flow velocity and detection of emboli by applying the ultrasound probe to the temporal, orbital, or greater occipital foramen. TCD is widely used for the evaluation of cerebral vasospasm after subarachnoid hemorrhage, early detection of patients with arterial stenosis and the check of brain death. However, measurements often become difficult in elderly women[1]. Among various factors for this problem, we focused on the effect of the skull bone on the ultrasound penetration into the brain. Especially, the effect of the temporal bone structure was investigated. Using a 2D digital bone model, wave propagation through the skull bone was investigated by the Finite-Difference Time-Domain (FDTD) method.

### 2. Bone model fabrication

The skull bone consists of three layers: the outer (cortical bone), diploe (cancellous bone), and inner (cortical bone). Cancellous bone consists of a network structure filled with bone marrow. A temporal skull bone model was created from the polygon model data of a healthy adult head[2]. Figure 1 shows the 3D image of the left temporal bone. Figure 2 shows cross-sectional views including the thinnest part of the bone. Three different bone models were created by changing the bone structure inside the skull. In model A, all parts of the bone were made of cortical bone. Model B was filled with trabecular bone created from CT images of the equine femur. Model C was the cortical bone filled with water. Model D does not include bone (water only). The bone volume fraction in the cancellous part of model B was 31.1 %.

Equation (1) shows the matrix of elastic constants of bone used[3].

$$c = \begin{pmatrix} c_{11} & c_{12} & 0 & 0 \\ c_{21} & c_{11} & 0 & 0 \\ 0 & 0 & c_{44} & 0 \\ 0 & 0 & 0 & c_{44} \end{pmatrix} \qquad (1)$$

In this study, we assumed a homogeneous and isotropic elastic properties in bone. $C_{11}$ was estimated using the ratio of the wave velocities in the axial and radius direction[4]. $C_{44}$ was estimated assuming Poisson's ratio of 0.33[5].

### 3. FDTD simulation

A two-dimensional elastic FDTD method was used as a simulation method. Here, attenuation is not considered. Spatial and time resolutions of the FDTD simulation were 14 µm and 2.5 ns, respectively. The longitudinal wave velocity and density of water were 1500 m/s and 1000 kg/m$^3$, respectively.

Figure 3 shows a simulation model. A transmitter (length : 20 mm) was placed on the outside of the bone model. The transmitter was an array of 100 transducers to control the phase for focusing the wave

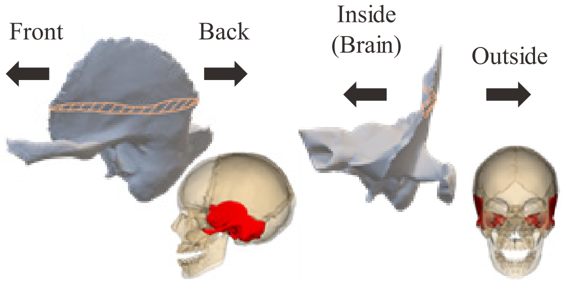


Fig. 1 The 3D models of left temporal bones.

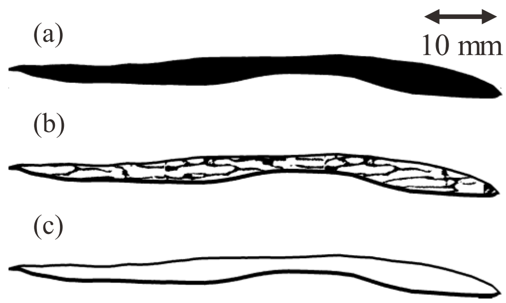


Fig. 2 The 2D models of left temporal bones.

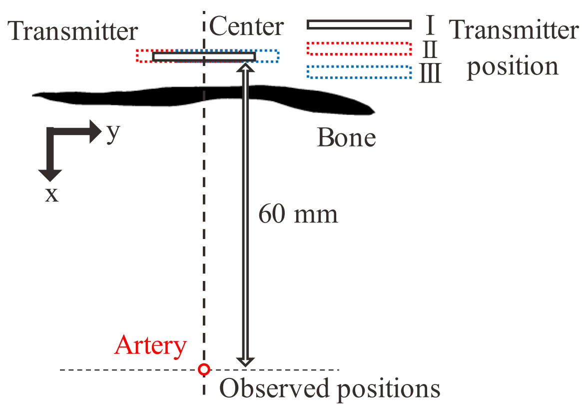


Fig. 3 Simulation conditions.

near the artery. Ultrasound was irradiated from three different positions. First, ultrasound was irradiated to the center of the temporal bone model (Position Ⅰ). In the other positions, the transmitter moved 4 mm to the left or the right (Positions Ⅱ and Ⅲ). The receiver array was set 60 mm away from the transmitter. The input waveform to the transmitter was a single sinusoidal wave with a frequency of 2 MHz with Hann window.

## 4. Results and Discussion

Figure 4 shows observed waves which passed through the bone model A. There are two separated waves. The first wave was the direct wave from the transmitter, and the second wave was the multiply reflected wave in the bone.

Figure 5 shows amplitude distribution of the first waves in the cases of models A and D (Position Ⅰ). Due to the bone complicated shape, the focusing area of ultrasound changed in the model A. High amplitude was not measured near the artery.

Table 1 shows the observed maximum amplitudes of the first waves. The cancellous structure attenuated the amplitudes strongly (model B). During the TCD measurement, the transmitter prove is often moved by the observer. However, the effects of transducer positions were small. The small parallel shift of the transducer position did not improve the amplitude dramatically.

Figure 6 shows the amplitude distribution of the first and second waves in the model A (Position Ⅰ). Compared to the first wave, the highest second wave amplitude wave was measured at position -20 mm from the artery. The multiply reflected waves in the bone may be refracted due to the bone shape.

## Conclusion

The effects of skull bone structure on TCD measurements were investigated by the FDTD simulation. As a result, the sound pressure near artery changed due to the bone structure. The inside cancellous bone decreased the wave amplitude dramatically, telling the possible effects of cancellous part on TCD measurements. Osteoporosis affects the bone volume fraction in the cancellous part. Our results possibly indicate the effects of osteoporosis on TCD.

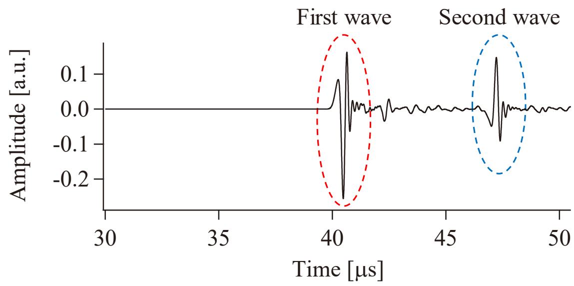


Fig. 4 Observed waveforms at the artery position in bone model A (Transmitter position Ⅰ).

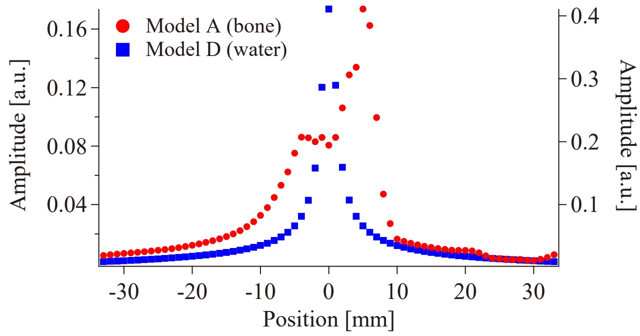


Fig. 5 Relationships between receiver position and maximum amplitude of first wave.

Table 1 Maximum amplitude of the first wave and maximum amplitude position in each model.

(a) Maximum amplitude. [a.u.]

| | Position Ⅰ | Position Ⅱ | Position Ⅲ |
|---|---|---|---|
| Model A | 0.196 | 0.173 | 0.171 |
| Model B | 0.034 | 0.028 | 0.031 |
| Model C | 0.121 | 0.118 | 0.118 |
| Model D | 0.764 | 0.740 | 0.740 |

(b) Maximum amplitude position. [mm]

| | Position Ⅰ | Position Ⅱ | Position Ⅲ |
|---|---|---|---|
| Model A | +5.0 | +5.0 | +5.0 |
| Model B | +2.0 | 0.0 | +2.0 |
| Model C | 0.0 | 0.0 | 0.0 |
| Model D | 0.0 | 0.0 | 0.0 |

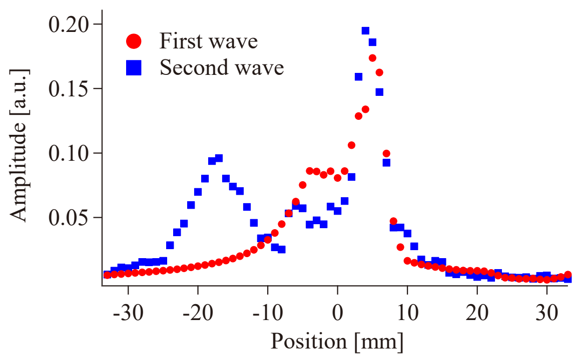


Fig. 6 Relationships between receiver position and maximum amplitude of the first wave and second wave.

## Reference

1. J. Kollar, et al.: Cerebrivasc Dis.,**17**, (2004) 61.
2. 3DCG head data base developed by Department of Neurosurgery, The University of Tokyo, https://brain-3dcg.org/.
3. J. L. Rose: *Ultrasonic Waves in Solid Media*, (CAMBRIDGE, 1999) p. 367.
4. Y. Yamato, et al.: Calcif. Tissue Int., **82**, (2008) 162.
5. T. H. Smit, et al.: J. Biomech., **35**, Issue 6, (2002) 829.