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Ultrasound Propagation Paths in Cancellous Bone with an Oblique Trabecular Orientation
斜めの骨梁配向を有する海綿骨中における超音波伝搬経路

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1. Introduction

Cancellous bone has a complex trabecular structure, which can largely affect ultrasound waves propagating in the bone. It was demonstrated that two waves called as "fast and slow waves" could travel in the direction parallel to the trabecular orientation,[1] and the investigation of this unique phenomenun is important to sufficiently elucidate the ultrasound propagation in cancellous bone. In previous studies,[2,3] the propagation properties of the fast and slow waves were investigated by using stratified cancellous bone phantoms composed of periodically alternating trabecular and water layers. As a result, it was suggested that the effects of the trabecular structure on both wave amplitudes at the oblique incidence to the major trabecular orientation could depend on the propagation paths.[3] Precise determination of the propagation path is considered to connect with accurate derivation of the wave properties.

In the present study, the propagation paths of the fast and slow waves in cancellous bone with an oblique trabecular orientation were investigated using finite-difference time-domain (FDTD) simulations with realistic cancellous bone models reconstructed from a three-dimensional (3D) microcomputed tomographic (μCT) image.

2. Simulation Method

A grayscale image of bovine cancellous bone with an oriented trabecular structure at a porosity of 0.82 was obtained by a 3D μCT system with a spatial resolution of 57 μm. The 5.7 mm cubic portions of the image were cut at rotation angles of 0 - 40 deg on the axis perpendicular to the major trabecular orientation, as shown in **Fig. 1**. From the cut images, five cancellous bone models with various trabecular-oriented angles were constructed by downgrading from the grayscale to binary values representing the trabecular and pore parts.

The region of the simulation model was 9.7 × 5.7 × 5.7 mm^3, in the middle of which the cancellous bone model was allocated, and the other was the water region. The transmitting and receiving flat surfaces with a 1.14 mm diameter were placed on the planes separated by 9.7 mm. The transmitting surface was fixed at the center on the plane and the receiving surface was moved at distances of 0.57 mm in the direction parallel to the plane and perpendicular to the rotation axis, as shown in Fig. 1. As for the excitation condition, a pulsed particle displacement with a center frequency of 1 MHz in the direction perpendicular to the transmitting surface was inputted at the points on the surface. The summation of the pressures at the receiving points was outputted.

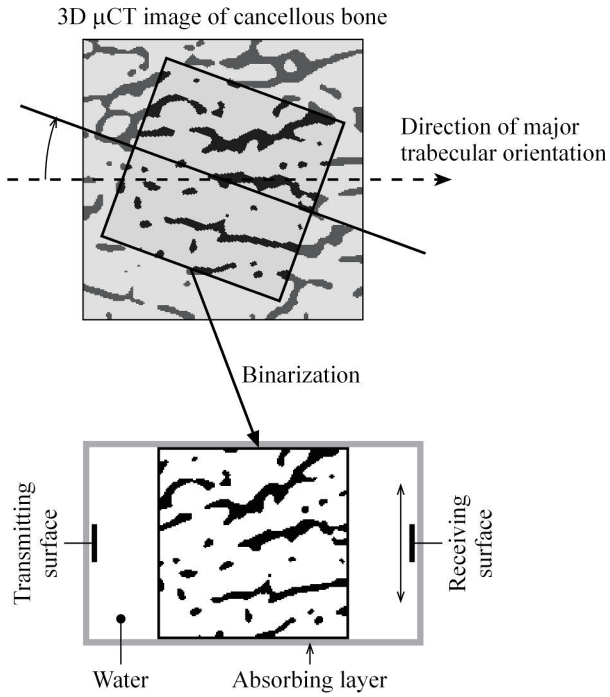

Fig. 1 Schematic of simulation model for ultrasound propagation through cancellous bone with an oblique trabecular orientation.

3. Simulated Results and Discussion

For each of five cancellous bone models, fast and slow waves at various positions of the receiving surface were simulated using an FDTD method. The amplitudes of the fast and slow waves, which were assumed to be the first and second positive peak amplitude of the respective waves because of

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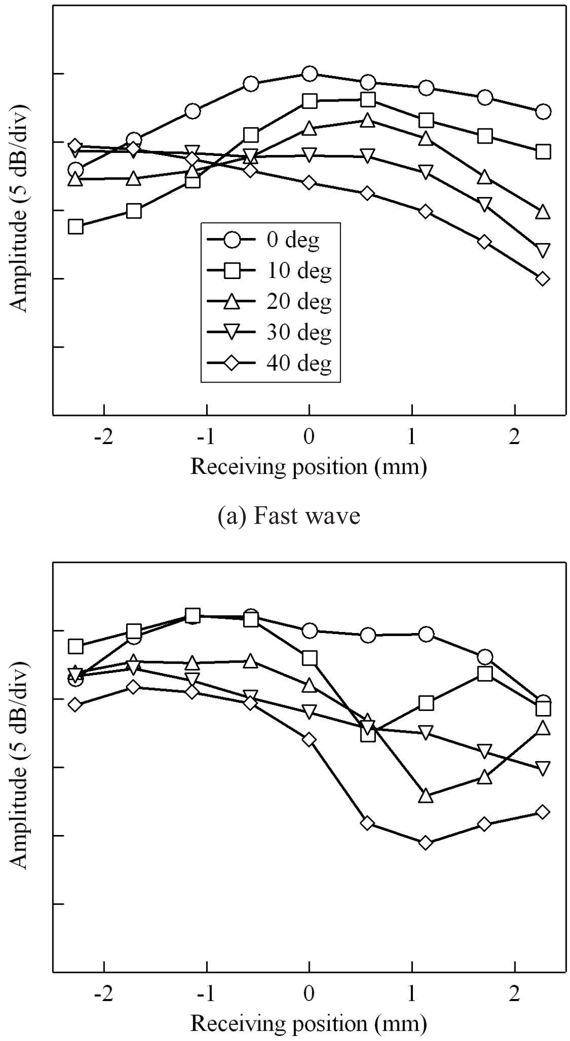
the overlap of these waves, were measured from the simulated waveforms. The variations in the measured amplitudes with the receiving position are shown in **Fig. 2**. In Fig. 2, zero value of the receiving position indicates the receiving surface locating at the center position, and the positive and negative values respectively indicate the locations at the upper and lower positions. As shown in Fig. 1, the direction between the transmitting and receiving surfaces becomes closer to the direction of the major trabecular orientation in the cancellous bone model with an oblique trabecular orientation as the receiving position shifts upward.

In Fig. 2(a), the fast wave amplitude at the trabecular-oriented angle of 0 deg is maximum at the receiving position of 0 mm. As the oriented angle increases up to 20 deg, the maximum position becomes to shift upward, which means that the fast wave propagates along the major trabecular orientation. Above 20 deg, however, the fast wave amplitude increases with decreasing the receiving position, which means that the fast wave easily propagates in the direction perpendicular to the trabecular orientation. In Fig. 2(b), the slow wave amplitude at the oriented angle of 0 deg is almost symmetrical between the upper and lower receiving positions. As the oriented angle increases, however, the amplitude at the lower position becomes larger than that at the upper position, which means that the slow wave propagates across the orientation.

In the present study, it was shown that, at an oblique angle of the major trabecular orientation, both the fast and slow waves trended to propagate perpendicular to the trabecular orientation. In the previous study using stratified cancellous bone phantoms,[3] the experimental results showed that the fast wave could propagate along the orientation and that the slow wave propagation slightly transited to the propagation across the orientation, which are different from the present results. This is because the trabecular structure in the actual cancellous bone, unlike the ideal structure of the phantom, is not perfectly oriented. The propagation paths of the fast and slow waves are considered to largely depend on the strength of the orientation, and therefore, more investigations using many cancellous bone models with various structures are required.

4. Conclusions

The propagation paths of the fast and slow waves propagating through cancellous bone were numerically investigated using FDTD simulations. From the variations in the simulated amplitudes of the fast and slow waves with the receiving position, it was shown that both waves trended to propagate perpendicular to the major trabecular orientation.



(b) Slow wave

Fig. 2 Simulated results of variations in fast and slow wave amplitudes with receiving position, for cancellous bone models with various trabecular-oriented angles.

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