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The effect of three dimensional trabecular frame structure on the fast wave velocity in bovine cancellus bone

ウシ海綿骨中の３次元骨梁構造と高速波音速の
異方性について

Somiya Hiroki[1‡], Katsunori Mizuno[1], Tomohiro Kubo[1] , Mami Matsukawa[1] ,
Takahiko Otani[1], Yoshiki Nagatani[2] ([1]Doshisha Univ.; [2]Kobe City Coll. Tech.)
宗宮弘樹 [1‡], 水野勝紀 [1], 久保智弘 [1], 松川真美 [1], 大谷隆彦 [1], 長谷芳樹 [2] ([1] 同志社大;[2] 神戸高専)

1. Introduction

In recent years, quantitative ultrasound (QUS) has become an important technique to assess the status of bone. One attempt is the measurement of cancellous bone, which is a good indicator for the osteoporosis. This bone, however, is anisotropic, heterogeneous and composed of complicated network structure called trabeculae in the bone marrow, which causes the complex wave propagation. We have reported the characteristic wave propagation of two longitudinal waves in the cancellous bone, the fast and slow waves [1]. The fast wave especially propagates through trabecular parts and is an important parameter to assess the structural anisotropy of the cancellous bone [2].

In this study, we investigate on the characteristic wave propagation in the cancellous bone, from the measurement of fast wave velocity using spherical specimens.

2. Materials and methods

2. 1 Specimen preparation

A spherical cancellous bone specimen was obtained from the left femur of a 30-month-old bovine. It was taken out from the distal part as shown in **Fig. 1**. The specimen, 12 mm in diameter, was defatted before the measurements. The structure images of the specimen were obtained using X-ray micro CT (Shimadzu, SMX-160CTS). The structural parameters (mean intercept length: MIL) were obtained by the 3D-Bon software (Ratoc). MIL parameters provide information on the angle and length of predominant trabeculae and orthogonal trabeculae. The direction of the maximum MIL parameter showed a small tilt (10 degrees) from anterior to posterior direction. Secondary maximum direction was distal to proximal direction (bone axis). Then, this specimen seems to have anisotropic lamellar structure (**Fig. 2(b)**). For ultrasonic measurement, we defined the predominant direction as the starting point at the measurement ($\theta = 0^{\circ}$, $\phi = 0^{\circ}$).

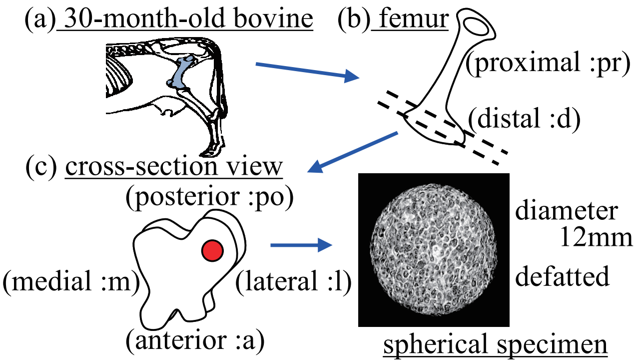
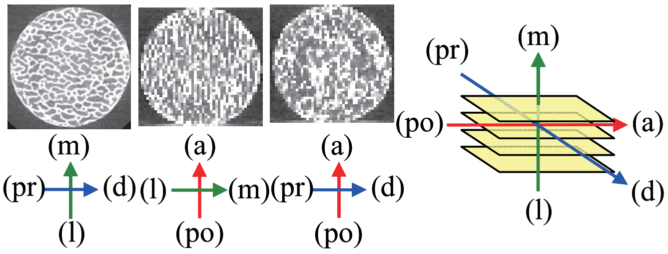


Fig. 1 Position of specimen in the femur.



(a) Cross section views (b) Lamellar model

Fig. 2 Structure of the spherical specimen.

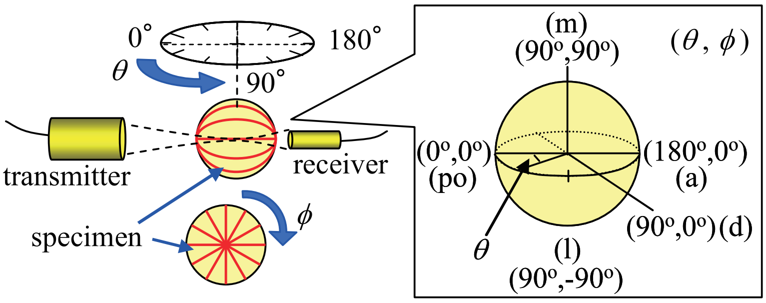


Fig. 3 Procedure of ultrasonic measurement, with the definition of incident angle (θ, ϕ)

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e-mail:mmatsuka@mail.doshisha.ac.jp

2. 2 Measurements

Longitudinal wave velocities were measured using a conventional ultrasonic pulse technique. A PVDF focus transmitter (diameter 20 mm, focal length 40 mm) and a flat PVDF receiver (diameter 10 mm) were used in this experiment. Both transducers were mounted coaxially with distance of 60 mm. A single sinusoidal signal (1 MHz, 50 Vp-p) was applied to the transmitter. The received signal was amplified by a 40-dB preamplifier. The measured specimen was placed in the focal zone of the sound field. By rotating the specimen, we obtained the velocity changes due to the acoustic incident angle to the bone geometry. The measurements were done at each rotation angle θ or ϕ of 10 degrees (**Fig. 3**).

3. Results and discussion

We could not find clear separation of fast and slow waves. In **Fig. 4(a)**, a wave that passed through water is shown. The wave propagation in bone was always faster than that in water, indicating the existence of fast waves. We focused on this fast wave propagation in the cancellous bone.

Figure 5 shows periodic changes in the fast wave velocity as a function of angle θ at each angle ϕ. The fast wave velocities clearly depended on θ. Changes were different depending on the angle ϕ. At the angle $\phi = 0^\circ$ where the change was the smallest, the difference between the maximum and minimum values was 260m/s. At this angle ϕ, wave always propagates in parallel to the lameller shown in **Fig. 2(b)**. The small velocity difference reflects the in-plane anisotropy lameller. Regardless of the angle ϕ, wave velocity showed maximum at angle $\theta = 0^\circ$ or 180°.

Figure 6 shows changes in the fast wave velocity at angle $\theta = 90^\circ$. At angle $\phi = 0^\circ$, wave velocity became maximum and wave propagated in parallel to the lameller. At angle $\phi = 90^\circ$, wave velocity was minimum, showing the wave propagation orthogonal to the lameller.

The MIL parameters were maximum in the anterior to posterior direction, and minimum in medial-lateral direction. Velocity results are reasonable compared with the MIL parameters.

4. Summary

The anisotropy of fast wave velocity in bovine cancellous bone was investigated. Wave velocity changes due to the acoustic incident angle, showing the acoustic anisotropy.

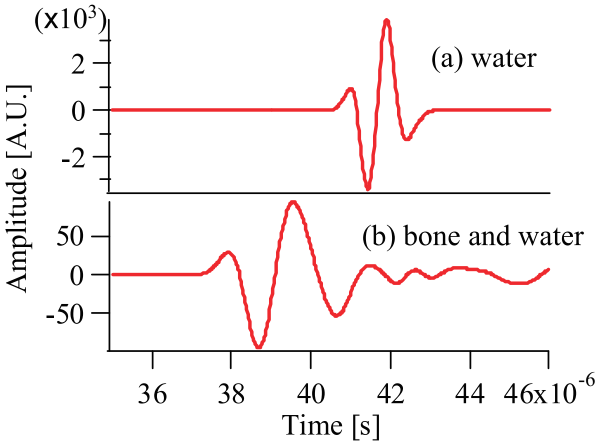

Fig. 4 Typical examples of observed waveforms.

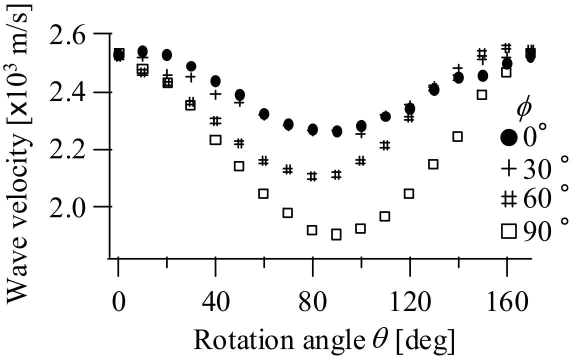

Fig. 5 Periodic changes of fast wave velocity.

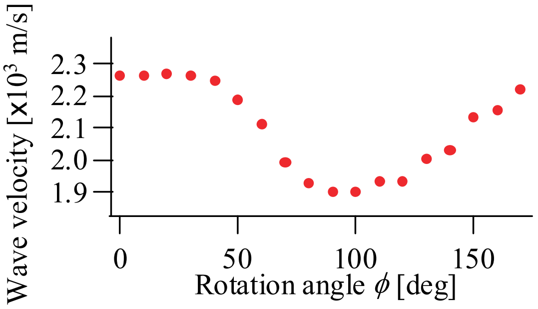

Fig. 6 Periodic changes as a function of ϕ at $\theta = 90^\circ$.

Acknowledgments

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