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Induced electrical potentials in cortical bone under shear ultrasound exposure

横波超音波照射下における皮質骨中誘発電位の検討

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1. Introduction

Recently, the low intensity pulse ultrasound (LIPUS) technique is used for the healing of bone fractures. The LIPUS technique uses pulsed ultrasound from 1.5 to 3.0 MHz. The ultrasound is considered to stimulate bone cells and to promote the healing of bone fracture. However, the intial mechanism of ultrasound effects on bone has not been clarified yet.

In 1953, Fukada and Yasuda have reported that the mechanical stress in the kHz range induces electrical potentials in bone [1]. Although recent mechano-biological studies have reported mechano-sensing cells in the low frequency range, one expected mechanism of the induced electrical potentials in the MHz range is the piezoelectricity of collagen or hydroxyapatite (HAp) in the bone matrix. Then, we have fabricated ultrasound transducers using bone as piezoelectric devices. We could observe longitudinal ultrasound as the output of the electrical potentials [2-4].

Bone is mainly composed of collagen and HAp. The hard and dense cortical bone shows strong elastic anisotropy due to their orientations [5]. This attributes to the complicated ultrasound propagation and piezoelectricity in bone. The object of this study is to investigate the characteristics of piezoelectricity in the bovine cortical bone by shear ultrasound irradiation.

2. Material and Methods

Figure 1 shows the preparation method of the bone transducers. Cortical bone samples were extracted from the mid-femoral shaft of a 26 month-old bovine and were processed into circular plates. Three kinds of circular plate cortical bone samples were cut normal to radial, tangential or bone axis directions. The diameters and thicknesses of these samples were 10.0-11.0 and 3.00 ± 0.01 mm, respectively. Using these plate samples as piezoelectric materials, we have fabricated bone ultrasound transducers.

A shear wave transducer (Japan Probe) was used as a transmitter and handmade bone transducers were used as receivers. An acrylic cube was adhered as a delay line between the transducers. These were adhered using a contact medium (SHN-B25; Taiyo Nippon Sanso Gas & Welding) as shown in **Fig. 2**. A function generator (33250A; Agilent Technologies) generated 10 cycles of the sinusoidal wave at 2.0 MHz, which were amplified to 70 V_{pp} by a bipolar power supply (HAS 4101; NF). The polarization plane was changed and the wave propagation direction was kept. The received signal was amplified 40 dB by a pre-amplifier (BX-31A; NF) and observed by an oscilloscope (DPO3054; Tektronix). The bone transducers were rotated at each 10 degrees to check the anisotropy.

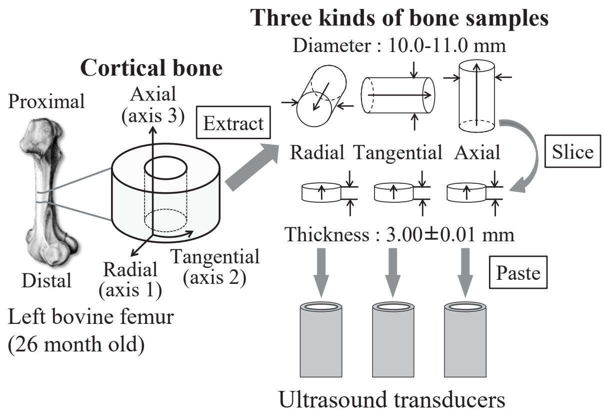

Fig. 1 Preparation of samples.

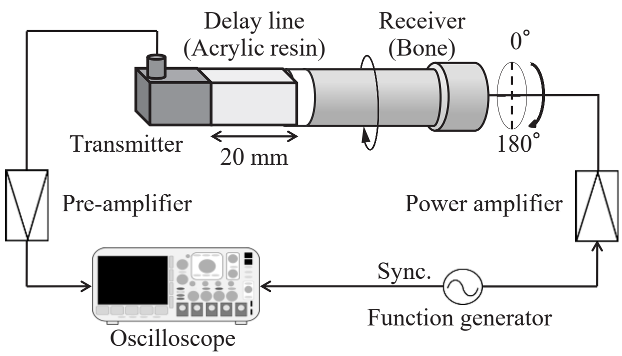

Fig. 2 Experimental system.

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3. Results and Discussion

Figure 3 shows observed waveforms measured by the bone transducer of the radial sample. We could observe shear ultrasound waves by the bone transducer. The amplitudes showed maximum at 0 and 180 degrees, whereas they showed minimum at 90 and 270 degrees. It means that, the sensitivity was high when the polarization plane of the shear wave was in the axial direction rather than the tangential direction.

Next, we measured the waves by rotating the bone transducers at each 10 degrees. **Figure 4** shows relationships between the induced electrical potentials and wave polarization directions. In **Figs. 4 (a) and (b)**, the amplitudes showed maximum in the axial directions (d_{15}, d_{24}), whereas they showed minimum in the radial and tangential directions (d_{16}, d_{26}). It has been reported that d_{16} and d_{26} were 0 pC/N in low frequency mechanical studies [6]. However, the small induced electrical potentials were also observed when the polarization plane was in the radial and tangential directions. Then, we measured the HAp crystal orientation in the axial sample using the X-ray diffraction technique (Philips X-Pert Pro MRD). The orientation of HAp crystal in the bone sample was inclined about 2 degrees from the bone axis. The data suggest that bone anisotropy due to the alignment of collagen and HAp has a clear effect on the induced electrical potentials. Since the HAp crystal orientation was slightly tilted from the axial directions in bovine bone, the induced electrical potentials seemed to be observed in all axes.

Figure 4 (c) shows a relationship between the induced electrical potentials and wave polarization directions in the axial sample. The radial-tangential plane of the cortical bone has been reported to be isotropic. Accordingly, the amplitudes of induced electrical potentials are expected to be constant at all angles. However, in our results, the amplitudes showed maximum in the tangential direction and minimum in the radial direction. Yamato has reported the longitudinal velocity in the radial direction was 3,460 ± 78 m/s and that in the tangential direction was 3,676 ± 142 m/s [5]. It indicates that this plane was slightly anisotropic, then, the amplitudes of induced electrical potentials seemed to change owing to the polarization plane.

4. Conclusion

We investigated the induced electrical potentials in the cortical bone by shear wave irradiation. Consequently, the induced electrical potentials changed due to the propagation and wave polarization directions in the bone samples. These results also indicate that there are appropriate irradiation directions of ultrasound to generate electrical potentials.

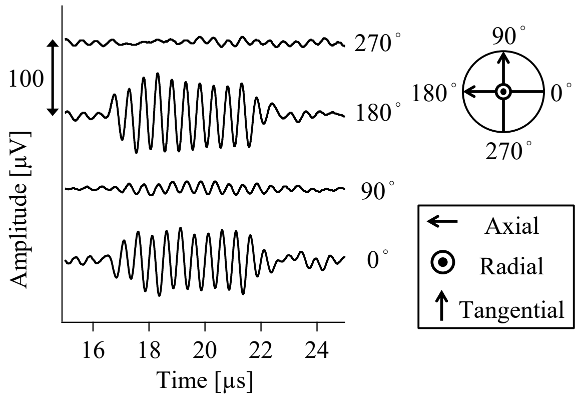

Fig. 3 Observed waves of radial sample.

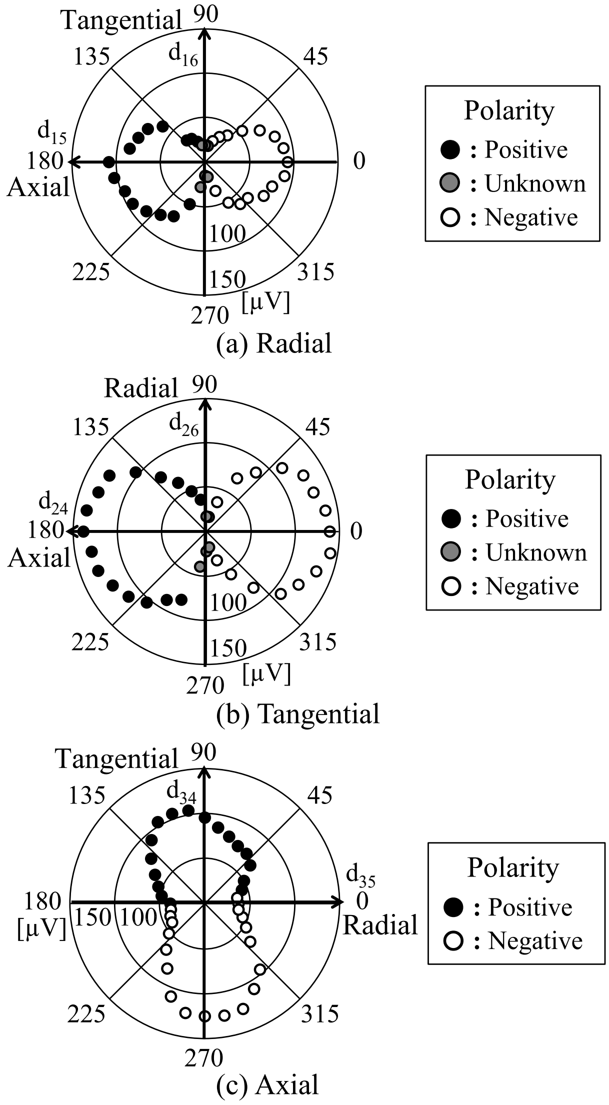

Fig. 4 Relationships between the induced electrical potentials and wave polarization directions.

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