1P5-4

Longitudinal ultrasound radiation from cortical bone

皮質骨から放射される縦波超音波

Taiki Makino[1‡], Tsukasa Nakamura[1], Leslie Bustamante[1], Daisuke Koyama[1], Shinji Takayanagi[2], and Mami Matsukawa[1] ([1]Doshisha Univ.; [2]Nagoya Inst. Tech.)
牧野 大輝 [1‡], 中村 司 [1], Leslie Bustamante [1], 小山 大介 [1], 高柳 真司 [2], 松川 真美 [1]
([1] 同志社大, [2] 名工大)

1. Introduction

Piezoelectricity in bone in the low frequencies is well known after Fukada and Yasuda's studies of induced electrical potentials by mechanical stress [1]. The induced electrical potentials stimulate bone cell and promote bone remodeling. They also pointed that the induced electrical potentials came from the piezoelectricity of collagen and supposed that the structure of the collagen in the bone seems hexagonal. In order to confirm the induced electrical potentials in the MHz range, we have fabricated ultrasound receivers using cortical bone as piezoelectric devices. We could observe longitudinal ultrasound as the output of the transducer [2].

Collagen and HAp, the main components of bone, are oriented along the bone axis direction. The hard and dense cortical bone shows strong elastic anisotropy due to their orientations [3]. This attributes to the complicated ultrasound propagation and piezoelectricity in bone. Matsukawa et. al. have reported that the polarity and the amplitude of the induced electrical potentials changed depending on the ultrasound propagation direction in bone [4]. In this study, we have fabricated ultrasound transducers using cortical bone samples extracted from the bovine femur and evaluated the longitudinal ultrasound radiation from cortical bone transducer in the MHz range.

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 34 month-old bovine and were processed into circular plates. Five circular plate cortical bone samples were cut normal to radial (Type A), tangential (Type B), axial (Type C), 45° directions from tangential-axial plane (Type D) or 45° directions from radial-axial plane (Type E). The diameters and thicknesses of these bone samples were 10.5-11.0 and 1.00 ± 0.01 mm, respectively. Using these bone samples as piezoelectric materials, we have fabricated ultrasound (bone) transducers.

----

mmatsuka@mail.doshisha.ac.jp

The handmade bone or two PVDF flat (diameter: 10 mm) transducers were used as a transmitter or a receiver. The distance between the transmitter and the receiver was 40 mm as shown in **Fig. 2**. A function generator (33250A; Agilent Technologies) generated a burst wave with 10 sinusoidal cycles in the frequency range from 0.8 to 2.4 MHz, which were amplified to 70 $V_{p\text{-}p}$ by a bipolar power supply (HSA 4101; NF). The signal was applied to a transmitter and irradiated to the surface of a receiver in degassed water. The received signal was amplified 20 or 40 dB by a pre-amplifier (BX-31A; NF) and observed by an oscilloscope (DPO3054; Tektronix). The receiving and transmitting sensitivities of bone transducers were obtained by the reciprocal method using the measured sound pressure and amplitudes of induced electrical potentials [5].

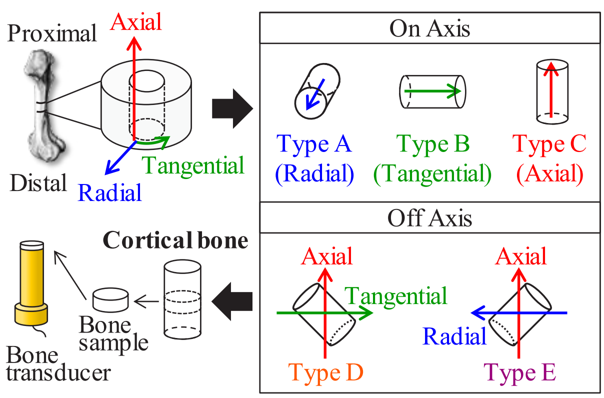


Fig. 1 Preparation of the bone transducers.

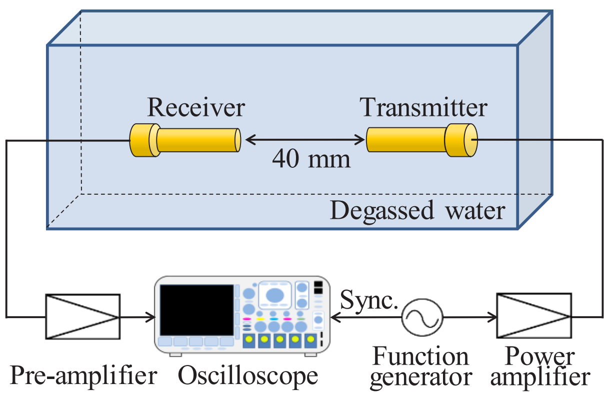


Fig. 2 Experimental system.

3. Results and Discussion

The observed waveforms by a PVDF transducer are shown in **Fig. 3**. We could observe longitudinal ultrasound radiation from all bone transducers. The sound pressure of ultrasound radiation from Type C bone transducer was about 10 $Pa_{p\text{-}p}$. The sound pressure from bone transducers was around 1/1000 of that radiated from the PVDF transducer.

Figures 4 (a) and (b) show the receiving and transmitting sensitivities of the bone transducers. The receiving and transmitting sensitivities of off axis bone transducers (Type D-E) were higher than those of on axis bone transducers (Type A-C). Matsukawa et. al. have irradiated longitudinal ultrasound to the side surface of circular bovine cortical bone in the tangential-axial plane. They have reported that the piezoelectric effect concerning d_{12} and d_{13}, and showed maximum at off axis angles with 90° rotation symmetry [4]. Although the piezoelectric properties in this study are d_{11}, d_{22} and d_{33}, we also found the increase at off-axis angles.

The transmitting sensitivities of bone transducers showed a peak at 1.725 MHz (Type A), 1.825 MHz (Type B) and 2.050 MHz (Type C). Yamato has reported the longitudinal velocity of bovine femur cortical bone in the radial direction: 3,460 ± 78 m/s, tangential direction: 3,676 ± 142 m/s and axial direction: 4,246 ± 124 m/s [3]. Since the backing material of our bone transducers was air, these peaks of sensitivities are possibly be half-wavelength resonance mode in the bone plate sample with 1 mm thickness. In fact, the resonance frequency of Type A (lowest velocity) was the lowest and Type C (highest velocity) showed the highest. The HAp crystal is oriented along the bone axis and related to the uniaxial anisotropy of velocity [6]. Therefore we measured the HAp crystal orientation in the bone samples of Type D and Type E using the X-ray diffraction technique (X-Pert Pro MRD; PANalytical). The c-axis orientations of HAp crystal were inclined about 53° (Type D) and 44° (Type E) from bone axis, respectively. The results tell us the velocity in the thickness direction of Type D sample is different from that of Type E sample. It results in the different peaks of Type D and E samples at different frequencies.

4. Conclusion

In this study, we could observe the longitudinal ultrasound radiation from cortical bone transducer in the MHz range. We confirmed that resonance frequency and receiving and transmitting sensitivities of bone transducers depended on the anisotropy.

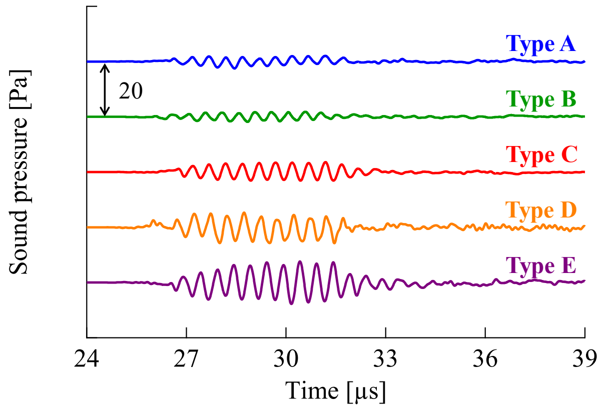
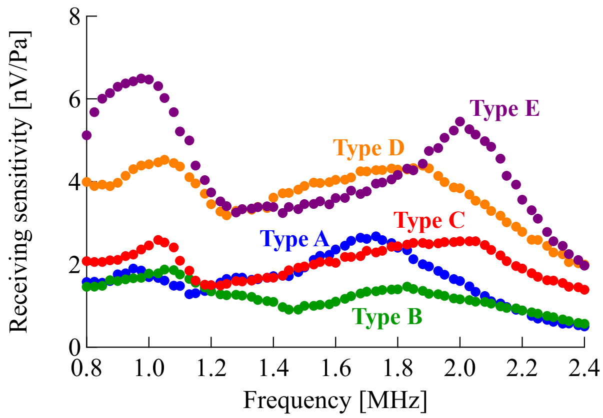
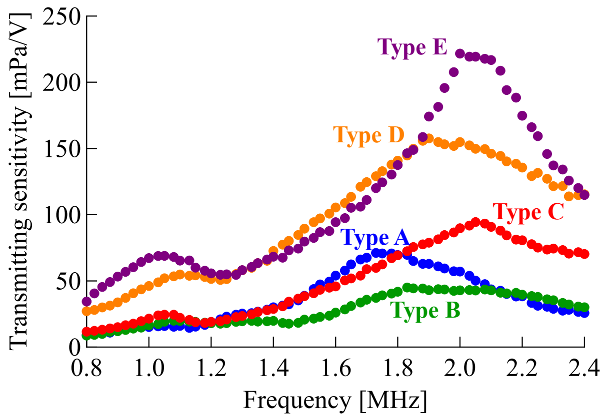


Fig. 3 Observed waveforms (2 MHz).
Transmitter : Bone transducers
Receiver : PVDF transducer



(a) Receiving sensitivities.



(b) Transmitting sensitivities.

Fig. 4 Frequency characteristics of bone transducers.

References

1. Fukada et al., J. Phys. Soc. Jpn., **12**, pp. 1158-1162 (1957).
2. Okino et al., Appl. Phys. Lett. **103**, 103701 (2013).
3. Yamato et al., Calcif. Tissue Int., **82**, pp.162-169 (2008).
4. Matsukawa et al., Appl. Phys. Lett. **110**, 143701 (2017).
5. H. Mermoz, Acustica, **8**, pp. 103-111 (1958).
6. T. Nakatsuji et. al., Jpn, J. Appl. Phys. **50**, 07HF18 (2011).