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Changes in photoacoustic signal due to surface microstructure of cortical bone

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1. Introduction

The number of diabetic patients is increasing due to lifestyle changes and aging society [1]. There is a case where diabetes decreases bone strength and increases the risk of fracture. According to National Institute of Health, bone strength depends on bone mineral density (BMD) and bone quality [2]. Bone quality includes factors such as bone remodeling, microstructure, microcracks, crystalline orientation etc. Diabetes possibly increases fracture risk due to bone quality deterioration.

To investigate the effects of diseases on bone, we should know the changes of bone matrix as well as microstructure. One interesting idea is the application of the Brillouin scattering technique [3] which can measure elastic properties in the small area, making use of the focused laser light. One another is the photoacoustic (PA) technique.

Therefore, this study focuses on the PA technique that can evaluate the material properties of bone matrix. PA uses short laser pulses whose electromagnetic energy is absorbed and converted into heat in the material, exciting ultrasonic waves due to thermoelastic expansion. In the case of appropriate light wavelength, soft tissue (skin) transmits laser light so that the PA technique can be used for in vivo evaluation of bone inside the body.

2. Samples and experimental method

A bovine femur (28 months old) was used as a measurement sample. The sample was cut out into a cuboid specimen (thickness direction: bone axis). The surface was well polished. For comparison, well-polished aluminum and polymer samples were prepared. To simulate the microstructure of the bone surface, a part of the surface of the polymer sample was scratched.

The photoacoustic measurement system used is shown in Fig. 1. The pulsed laser beam（Torus XS, Cobolt, 1064 nm, repetition frequency 1 kHz, pulse width 2.5±1.0 ns） was focused (spot diameter (FWHM): 60 μm). The beam passed through the center of a hollow concave ultrasonic transducer (Toray techno, custom made, focal length 15 mm) in degassed water. The photoacoustic wave generated by the laser beam was measured by concave transducer, amplified by 46 dB using an amplifier (SA-420F5, NF), and measured by an oscilloscope (DPO7254C, Textronix). Photo-acoustic waveforms were measured by moving the laser irradiation position with 20 μm intervals. The surface images of the samples were captured by an optical microscopy (Keyence, VW-300C).

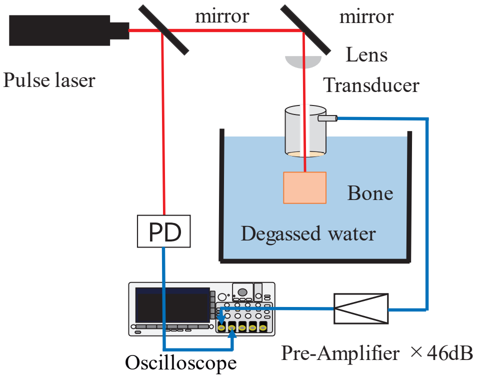

Fig. 1 Experiment system

3. Results and Discussion

Photoacoustic waveforms obtained from the cortical bone surface are shown in Fig. 2. 2D maps of the observed peak-to-peak values of the photoacoustic waves from the (a) aluminum (b) cortical bone samples are shown in Fig.3. The peak-peak values of the waves generated at the aluminum surface were almost constant (no site dependence), however, the peak-peak values of the waves at the cortical bone surface increased significantly due to the measurement site. One possibility of this difference may result from the microstructure at the bone surface. Figure 4 shows the cortical bone surface where we can see small irregularities due to the blood vessels. The amplitude of the photoacoustic wave increased especially in the small pores made by the vessel. However, it is unclear whether this amplitude increase is due to the physical properties of the bone or to the surface shape (small pores). Thus, we checked the effects of surface irregularity on the photoacoustic waves in the next step.

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The size of scratch of the polymer sample was about 46 µm in width. Depth could not be measured precisely. Photoacoustic waveforms from the polymer surface are shown in Fig.5. The amplitude of the waves increased near the scratch area, telling that the amplitude increase may come from the irregularities at the surface. In addition, according to the waveforms in Fig.5, some waves seem to be a superposition with slightly delayed pulse waves.

Figure 6 shows relationship between the peak – peak values of the observed waves and the position of the laser beam. We moved the position of the beam gradually from the flat area (distance 0 µm) to the scratch area. We should note here that the position is the center of the beam (spot diameter 60 µm). The amplitude actually increased near the gap. In Fig. 5, some waves (positions 20 - 60 µm) seem to come from a superposition with slightly delayed pulse waves. One possibility is that, near the gap, a portion of the laser light also generated waves in the small gap, which were observed as slightly delayed waves. We should check the depth of the scratch and the delayed time of the waves. Assuming the depth of the scratch is around 30~50µm, the time difference between the superposed waves is reasonable.

4. Conclusion

Photoacoustic waves from the bovine cortical bone surface were experimentally investigated. The results showed that, the bone surface microstructure affected the photoacoustic properties. In the next step, we would like to investigate the dependence of photoacoustic properties on surface pore structures, to study the relationship between bone microstructure and photoacoustic properties.

References

1) International Diabetes Federation, DIABETES ATLAS 10th edition, 2022.
2) NIH. J. A. M. A., 285, 785, 2001.
3) Tsubota, JASA Exp. Lett., 135, EL109, 2014.

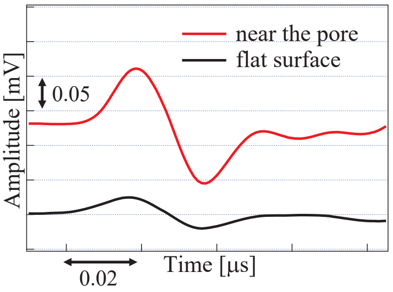
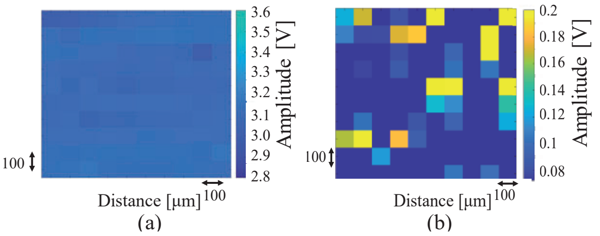


Fig.2 Observed waveforms from the cortical bone.



(a) (b)

Fig.3 Peak-peak amplitudes of waves from (a) aluminum and (b) bone.

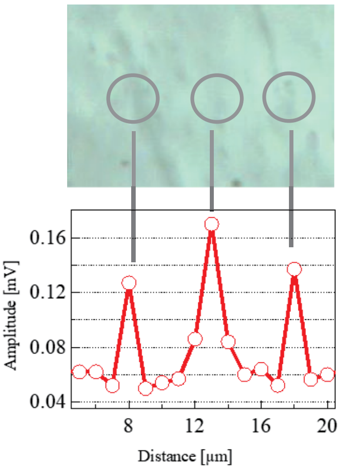


Fig. 4 Position-amplitude relation (bone).

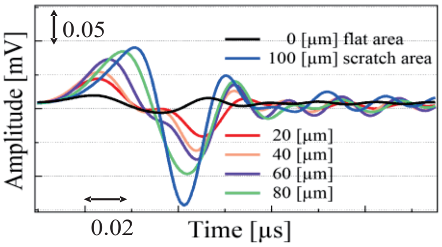


Fig. 5 Photoacoustic waveforms observed at different positions on the polymer sample.

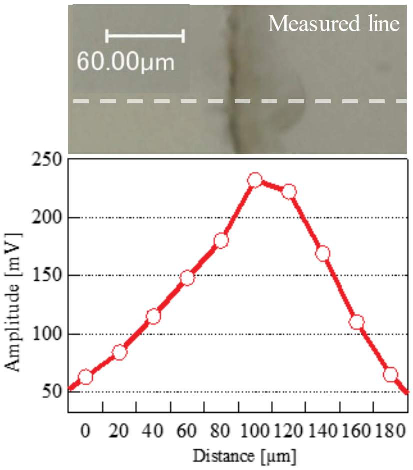


Fig.6 Amplitude changes due to the irradiation position.