Photoacoustic imaging of knee cartilage mouse using a semiconductor laser

半導体レーザを用いたマウス膝軟骨の光音響イメージング

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1. Introduction

In aging societies including Japan, the number of patients with osteoarthritis (OA) and rheumatoid arthritis (RA) is increasing in recent years. Early detection and treatment are important because these diseases prevent patients from walking. MRI or X-ray is used as inspection method of these ailments. Ultrasound (US) which enables real-time imaging is also applied in recent years [1]. However, each imaging modality has its merits and demerits. Here we propose a new idea to evaluate cartilage using photoacoustic (PA) phenomenon as a new imaging modality. PA imaging is a method to visualize deep tissues with high contrast which were not able to be observed by using optical imaging alone in the past modalities. The PA signal depends on the wavelength of the laser and absorption coefficient of the tissues. For example, 532 nm wavelength of the laser which is used in this study, the strong signals are generated from blood vessels [2]. In previous studies using YAG:Nd laser, the temporal resolution was limited by slower repetition time of the laser. Higher repetition rate is available by a semiconductor laser which may lead to shorten the time of measurement. In the present study, we develop a PA microscopy using a semiconductor laser for visualization of the knee cartilage in mice, and we clarify the PA characteristics of the knee cartilage by comparing with ultrasound microscopy.

2. Method

2-1. Photoacoustic imaging

PA imaging is a hybrid imaging modality based on optical and ultrasound imaging [3]. An ultra-short pulsed laser is illuminated to the biological tissue. When light energy is absorbed, a local temperature rise leads to a thermal-elastic expansion and the generation of a pressure wave (called a PA signal). The signal is then detected to image the internal optical absorption distribution.

PA signal is determined from absorption constant which depends on the laser's wavelength, light-scattering property, heat characteristic and elastic characteristic of an object. Among them, absorption constant is especially critical parameter which has a major effect on PA signal. PA signal caused by the laser can be expressed as

$$p_0 = \left(\beta c^2 / C_p\right)\mu_a F \quad (1)$$

where P_0 is pressure of thermal-elastic expansion, β [k^{-1}] is volume coefficient of expansion, c is sonic speed, C_P is specific heat [J/(Kg.K)], μ_a is absorption constant, F is light flux [J/cm] [4]. Absorption constant of tissue is defined physically, so the biological tissues are able to be quantitatively measured. Therefore, intensity of PA signal varies by each tissue.
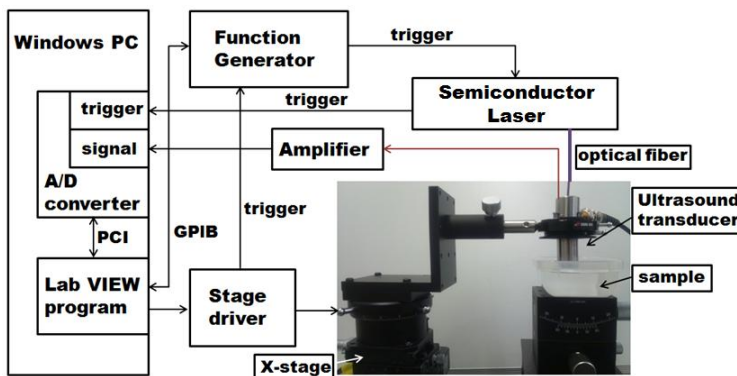

Fig.1 Block diagram of a PA microscopy
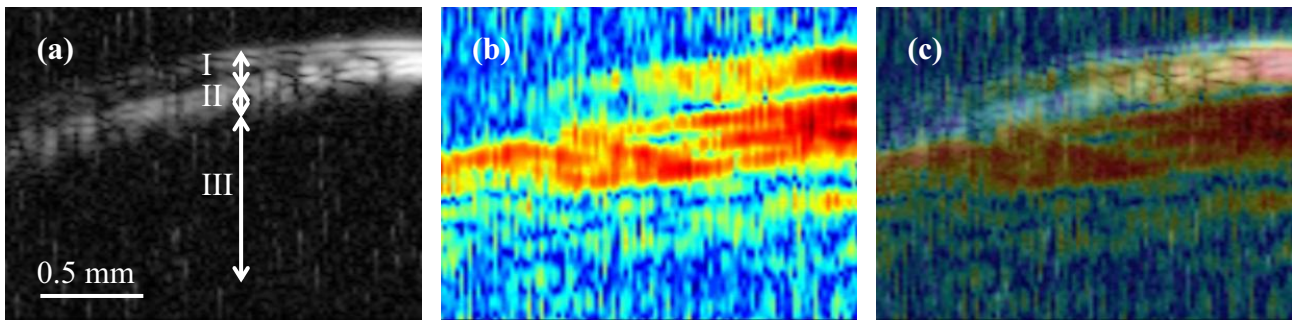

Fig.2 Ultrasound transducer

Fig.3 Observation of mouse knee cartilage (a) US imaging, (b) PA imaging, (c) merged image

2-2. Experimental setup

The block diagram of the system is shown in Fig. 1. Laser pulses were generated by a semiconductor laser (Hamamatsu Photonics K.K., L11038-02Y) with the repetition rate of 50 Hz. PA signal was received by a 50 MHz focused ultrasound transducer shown in Fig. 2. This had a hole in the central part to get through a light fiber in order to align light illumination and signal reception concentrically. Mechanical scanning of the transducer was realized by using an x-axis stage (Sigma-koki, SGSP20-20) and a stage-driver (Sigma-koki, Mark-202). A digitizer card (DP1400, Acqiris, Inc.) installed in the PC was used to acquire the PA signal with the sampling rate up to 1 GSample/s. Lab-VIEW program was used to control the stage-driver and the function generator (MF1944B, NF, Inc.) which sent a trigger to a semiconductor laser. Further data processing and analysis were conducted by using MATLAB program (Mathworks, Inc).

3. Results and discussion

Fig. 3 shows a PA tomography (a) and ultrasound tomography (b) of a mouse knee cartilage in water. In addition, figure.3(c) shows merged image of (a) and (b). A plane of 2 x 1.5 mm^2 was imaged at a scanning step of 20 µm. PA signals were averaged at 50 times to reduce a noise. The acquisition time of one image was 2 sec which was approximately five times as fast as using YAG-laser. In Fig. 3, Ist layer is cartilage, IInd layer is subchondral bone and IIIrd layer is a spongy bone in US imaging. The signal from the cartilage surface was weak and the signal from the surface of subchondral bone was strong in ultrasound imaging. On the other hand, signal from the cartilage was weak and the signal from the spongy bone was greater than that of subchondral bone in PA imaging.

The results indicate that the US reflection was strong at the surfaces of cartilage and subchondral bone because the difference of the specific acoustic impedance between neighboring layers was strong. On the other hand, the signal from the spongy bone was especially strong in PA imaging because the 532 nm laser light was more absorbed in spongy bone with higher vascular distribution than other tissues. Moreover the signal from the spongy bone was weak in US imaging because the US signal was attenuated at the subchondral bone.

4. Conclusion

In the present study, we were able to observe the knee cartilage of mice by PA imaging and to detect the PA signal from the spongy bone located deeper than the subchondral bone which was not observed by conventional US imaging. The result indicates future application of the PA imaging for the early detection of OA or RA in clinical settings.

References

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