Blood Circulation Variation Measurement Example

Measurement of time-series variation of blood circulation in peripheral parts of a hand

We measured time-series variations of blood circulation, using the Hadatomo™ Z photoacoustic microscope. Blood circulation within the dermis is influenced by the outside temperature, disease, and other factors. Time-series variations of the blood circulation can be measured with a laser Doppler blood flow meter. However, this method cannot observe the shapes of blood vessels, and information on depth cannot be obtained. In contrast, the photoacoustic imaging method can measure blood vessels noninvasively, visualizing the image of blood vessels with accurate information on depth. We measured time-series variations of blood circulation with the Hadatomo™ Z photoacoustic microscope by utilizing the theory that photoacoustic signals vary depending on the amount of Hemoglobin.

We measured eight healthy volunteers. To measure a peripheral part of the hand, we chose the fingertip of the little finger for measurement. The measurement area is 9 mm square, and the scan step is 30 μm. We used two laser wavelengths, 532 nm and 556 nm, for measurement.

Fig. 1 shows the protocol of the experiment. A subject submerses his/her hand and forearm into chilled water for one minute to chill the fingertip. Then we measured it with the Hadatomo™ Z. After measurement, we took photographs and measured the fingertip with thermography (FLIR ONE, by FLIR Systems). We warmed the forearm and hand with portable hot packs for ten minutes, then we again measured with Hadatomo™ Z, took photographs, and measured again with thermography.

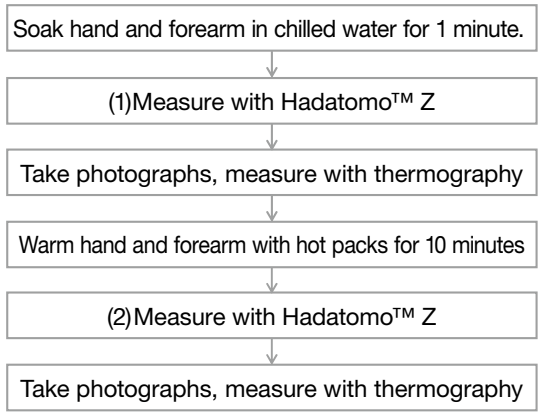

Fig. 1 Protocol of measurement

Fig. 2 shows examples of measured data. By observing the image obtained by thermography after chilling the hand, we could see that temperatures of fingertips were lowered (a1). In contrast, body temperatures increase after warming (b1). However, when we observe the outside photographs, variations in blood circulation due to chilling or warming cannot be observed (a2, b2). On the photoacoustic image after chilling, blood vessels within the dermis can be observed (a3). On the photoacoustic image after warming, brightness of the blood vessels is higher, so we can assume that the blood circulation is increased by warming, so that the photoacoustic signals increased (b3).

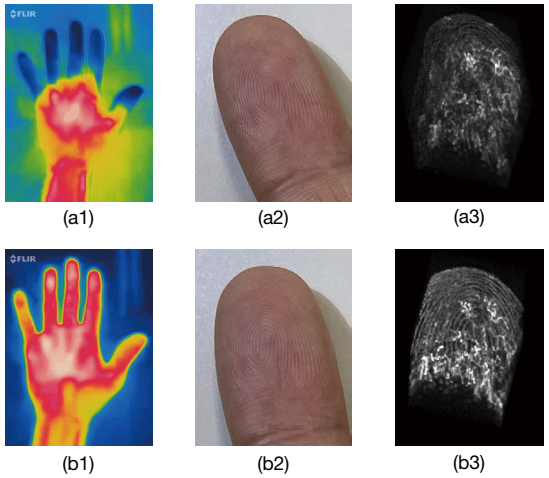

Fig. 2 Measurement examples
(a1, a2, a3) Measurement results after chilling,
(b1, b2, b3) Measurement results after warming,
(a1, b1) Measurement results of thermography,
(a2, b2) Outside photograph,
(a3, b3) Photoacoustic image of wavelength 556 nm

For the eight subjects, we compared the photoacoustic signals after chilling and after warming. We used the flow shown in Fig. 3 to verify the direction of depth for comparison. As the surface of the skin is curved, if we simply extract data in the depth direction, data of epidermis and dermis are mixed on a same depth. To avoid this, we detected surface data of the skin and executed a normalizing process. Then we set the ROI to an area of 6 x 6 mm in the center of the image. After chilling and warming, we counted the number of pixels from the photoacoustic signal, which contain more than a certain number of signals,

assuming them as the amount of Hemoglobin. We chose the center area for ROI, because we could not get signals at some areas at the edge of the image, depending on the shape of the finger. When the amount of Hemoglobin varies based on the variation of blood circulation, signal intensity of the photoacoustic signal should vary. Therefore, it is assumed that the amount of Hemoglobin (number of pixels) changes after chilling and warming. At the end of the experiment, we compared variations of Hemoglobin on every 200 μm in the depth direction for each subject.

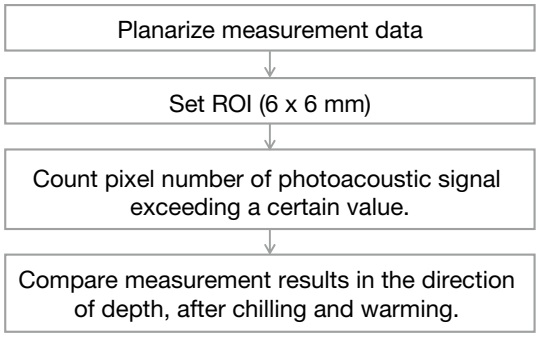

Fig. 3 Operation flow to compare photoacoustic signals

Fig. 4 shows example of tomographic images. These images are processed with planarization. We have set 6 mm square at the center of the image as ROI, so it means we analyzed the areas surrounded by yellow frames.

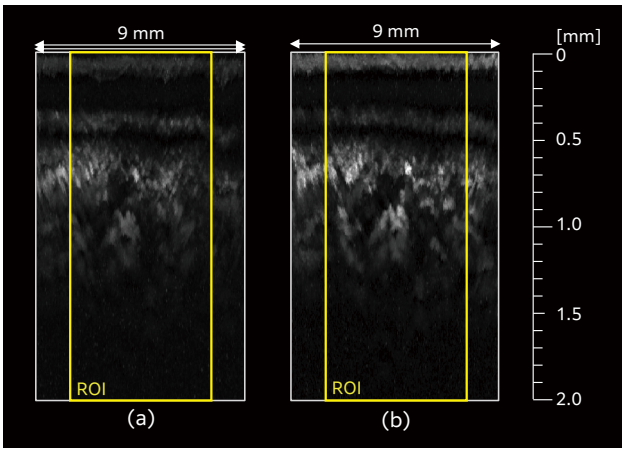

Fig. 4 Examples of photoacoustic tomographic image
(a) Measurement result after immersing in chilled water
(b) Measurement result after warming
The yellow frames show ROI areas during verification

Fig. 5 shows verification results for N = 8. The broken line in the figure connects the median of each depth. On the shallow area within the depth of 400 μm, variations are observed. The shallow area is the epidermis, so it is assumed that the signal values varied, affected by expansion of skin when immersed in the chilled water, or affected by slight deviation of the measured area location. In the area between 400 and 1000 μm depth, the amount of blood circulation increase or decrease varies largely. In contrast, in the area between 1000 μm and 1500 μm, though we see some variations among subjects, it is observed that the amount of Hemoglobin is increasing. The same tendency is observed in measurement results in Fig. 4, where signal intensity derived from blood vessel is increased at the depth around 1 mm. Because blood vessels in the upper area of the dermis are easily influenced by the outer temperature, they are largely influenced by individual differences. In contrast, in the deep area of dermis, the influence of outer temperature is small, so there is a possibility that the tendency of increasing amount of Hemoglobin is observed.

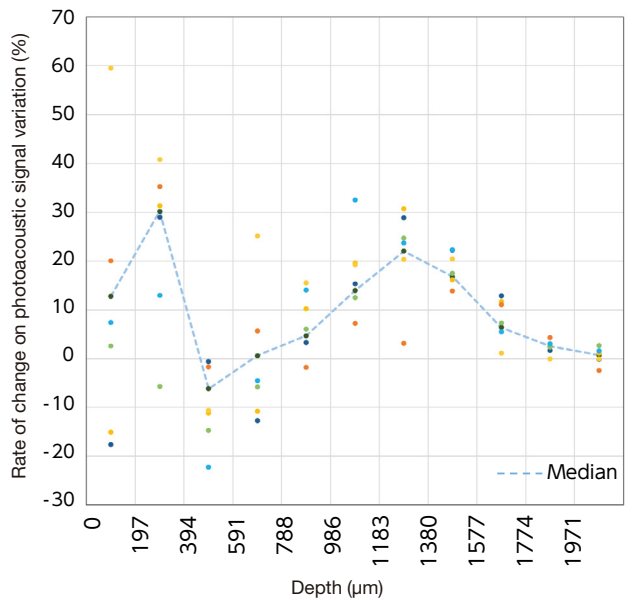

Fig. 5 Rate of change on amount of Hemoglobin versus depth, after immersing in chilled water and warming

As shown above, using the Hadatomo™ Z photoacoustic microscope, we could observe time-series variation of blood circulation around 1 mm from the surface of skin, which was difficult to observe using photographic imaging. By utilizing the ability to acquire information in the depth direction, there are possibilities that time-series variation of blood circulation can be observed in images never seen before.

Note that thickness of dermis differs from one individual to another, so the analysis data in the depth direction may contain these differences as errors. In this measurement, measurement setup errors after chilling or warming are also included. By reviewing and improving the measurement setup conditions or protocol for experiment, we may expect to conduct more precise verification.