2P5-12

Ultrasonic velocity change method utilizing the cooling effect of ultrasonic gel

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1. Introduction

We have investigated the Ultrasonic Velocity Change (UVC) method[1-4] as a non-invasive technique for identifying fatty regions in vivo, such as unstable vascular plaque and fatty liver. It exploits the distinctly different temperature dependence of ultrasonic velocity in water compared to other biological tissues. Our research so far has primarily focused on the human forearm. Through extensive experiments, we have confirmed that the UVC method can generate accurate and effective images based on echo data collected during ultrasonic warming [4]. However, we observed that the cooling effect of the ultrasonic gel often impacted the UVC image quality at the onset of warming. This finding led us to suspect that the cooling effect of the gel might be more significant than initially expected.

In this study, we aim to harness the cooling effect of the ultrasonic gel to induce temperature changes in the body, thereby generating UVC images of the forearm. We propose that utilizing the temperature changes induced by the ultrasonic gel's cooling effect may offer a safer alternative to warming for UVC imaging.

2. Method

2-1. UVC method

The UVC method utilizes the principle that the temperature dependence of ultrasonic velocity varies depending on the medium through which the waves travel. Specifically, near body temperature, the rate of ultrasonic velocity change is +1.9 m s^{-1} $°C^{-1}$ in water and -4.9 m s^{-1} $°C^{-1}$ in fat, respectively. This property enables noninvasive visualization of deep fatty regions in the body, such as unstable vascular plaques and fatty liver. The UVC method calculates the amount of shift by comparing two echo image data sets taken before and after a temperature change. It then highlights regions where the ultrasonic wave propagation speed has increased due to the temperature change in red and regions where it has decreased in blue. The resulting image is called a UVC image.

2-2. Experimental method

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Fig. 1 shows the experimental setup for UVC imaging of the human forearm. An ultrasonic array transducer (central frequency of 7.5 MHz, ALOKA, SSD6500) was positioned at the measurement site using a standoff, with a thin layer of ultrasonic gel as the coupling medium. The gel, kept refrigerated, had an initial temperature of approximately 5°C at the start of the UVC experiment. The standoff was filled with the ultrasonic gel, and an ultrasonic array transducer, along with a thermocouple, was installed. The thermocouple continuously monitored the gel temperature, and 270 echo images were captured at 9-second intervals for each 1°C temperature increase. UVC images were then generated by comparing pairs of echo images obtained at specific time intervals.

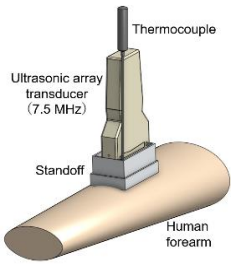

Fig. 1 Experimental setup for UVC imaging of the human forearm.

3. Results and discussion

Fig. 2 shows a B-mode image of the forearm of a healthy 23-year-old male. In this image, the gel within the standoff is visible from 0 mm to a depth of 3 mm, revealing the underlying skin surface and a layer of subcutaneous fat approximately 3 mm thick. Muscle tissue becomes apparent at a depth of 10 mm and beyond, with muscle striations extending from a depth of 20 mm to 30 mm and spanning laterally from 0 mm to 30 mm.

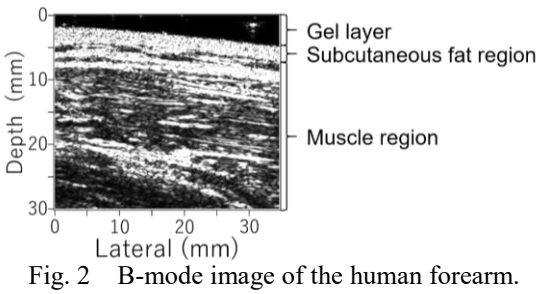

Fig. 2 B-mode image of the human forearm.

Fig. 3 shows UVC images of the human forearm obtained from 9 seconds of echo data immediately after the gel temperatures reached (a) 12 °C, (b) 17 °C, and (c) 22 °C, respectively. Thermocouples embedded in the ultrasonic gel recorded temperature changes of (a) 0.30 °C, (b) 0.12 °C, and (c) 0.04 °C over a 9-second period. In this case, the time difference between the paired images to obtain the UVC images was set to a time equivalent to two heartbeats. In the UVC image (a), blue is prominent in the muscle region. In contrast, the thin subcutaneous fat layer shows a small and less discernible shift due to temperature changes, but overall, it is shaded towards the red side. This color distribution suggests that both the subcutaneous adipose tissue and muscle regions were cooled by the ultrasonic gel. In UVC image (b), the color scheme of UVC image (a) is reversed, with light blue appearing in the subcutaneous fat region and light red in the muscle region, indicating a rise in temperature. These changes are believed to be due to blood flow responses aimed at increasing the temperature of the cooled skin surface. In contrast, UVC image (c) shows a mixture of red and blue across all areas, which is a typical example of a noisy UVC image reflecting tissue dynamics once temperature changes have reached a steady state. Therefore, it has been determined that controlling the temperature of the ultrasonic gel and the cooling time is expected to yield effective UVC images that accurately reflect biological responses.

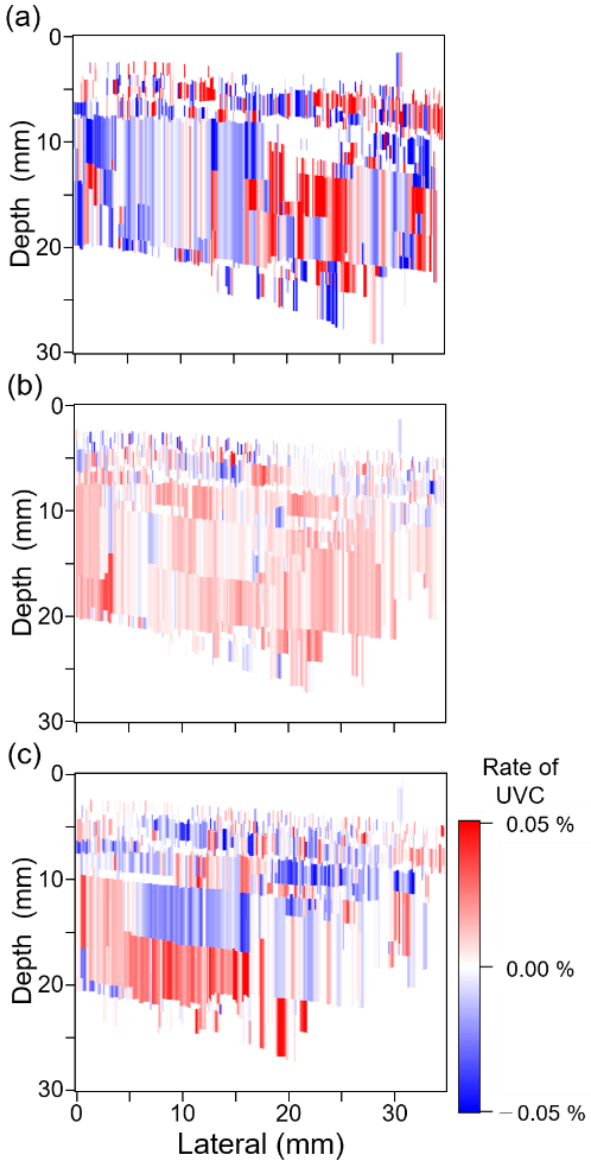

Fig. 3 UVC images of the human forearm. Each image was depicted from the echo data acquired during the 9 seconds immediately after the gel temperature reached (a) 12°C, (b) 17°C, and (c) 22°C, respectively.

4. Conclusion

By utilizing the cooling effect of the ultrasonic gel and applying the UVC method to the human forearm, it has been determined that controlling the temperature of the ultrasonic gel and the cooling time can potentially produce effective and safe UVC images. This technology is planned to be applied in the future for imaging carotid artery plaques.

Ethics

This study was approved by the Ethics Committee of Osaka Prefecture University.

References

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