Ultrasonic velocity change imaging for the human forearm

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1. Introduction

We have investigated the Ultrasonic Velocity Change method (UVC method) [1)] as a non-invasive approach for discriminating fatty areas (such as unstable vascular plaque and fatty liver) in vivo [2,3)]. The UVC method capitalizes on the contrasting temperature dependence of ultrasonic wave propagation velocity between water and fat regions. To date, we have developed a simulated vessel model with artificial unstable plaque embedded within the tissue mimic (TMM) phantom. Through extensive experiments, we have confirmed the feasibility of generating accurate and effective UVC images for this model. However, application of the UVC method to living body under tissue motion caused by heartbeat results in incorrect assessment of this method. In this study, we focused on applying the UVC method to the human forearm, an area relatively unaffected by the heartbeat, allowing us to compare UVC images before, during, and after warming. The objective of this research is to investigate the effectiveness of the UVC method when applied to living body.

2. Method

2-1. UVC Method

The UVC method relies on the principle that the temperature dependence of ultrasonic velocity varies with the medium through which ultrasonic waves propagate. Specifically, around body temperature, the temperature change rate of ultrasonic velocity in water is +1.9 m s^{-1} $°C^{-1}$, while in fat, it is -4.9 m s^{-1} $°C^{-1}$. This feature can be employed to noninvasively visualize deep fatty areas of the body, such as unstable vascular plaques and fatty liver. The UVC method calculates the shift amount based on the difference between two echo image data before and after the temperature change. Subsequently, it depicts areas where the propagation velocity of ultrasonic waves increased due to the temperature change in red, and areas where the propagation velocity decreased in blue.

2-2. Experimental Method

Fig. 1 shows the experimental setup for forearm UVC imaging. An ultrasonic array transducer (central frequency of 7.5 MHz, ALOKA, SSD6500) was placed on the human forearm using a standoff, and a gel layer with a thickness of 5 mm was injected as a coupling medium. An ultrasonic warmer (ITO, US-710) was positioned alongside the ultrasonic array transducer, ensuring that the warming and observation areas coincided. The forearm underwent a 1-minute warming session with the conditions set at 1 MHz frequency and 0.7 Wcm^{-2} output intensity. During each measurement process, 270 echo images were acquired over a 9-second interval. These measurements were repeated before, during, and after warming. Subsequently, UVC images were obtained using echo image pairs acquired with appropriate time differences.

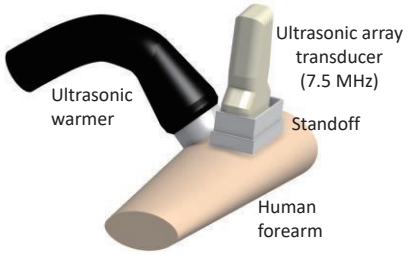

Fig. 1. Experimental setup for UVC imaging of the human forearm.

3. Results and discussion

Fig. 2 shows an example of a B-mode image of the human forearm. The image depicts the skin surface beneath the gel in the standoff and an area of subcutaneous fat located further below. To mitigate the effect of the heartbeat, measurements were taken in a region devoid of any blood vessels.

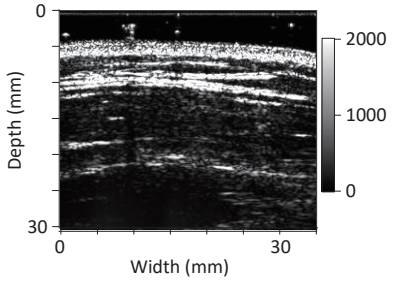

Fig. 2. B-mode image of the human forearm.

Fig. 3 shows the plot of averaged image correlation (Zero-mean Normalized Cross-Correlation: ZNCC) values as a function of the difference in image number between paired images. The plot is based on 270 echo-images captured over a 9-second period during the warming process, with the difference in image number varying from 1 to 269. The averaged image correlation value decreases

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as the difference in image number increases and exhibits periodic ripples. These ripples occur at intervals of approximately 35 image numbers, corresponding to intervals of about 1 second, and are attributed to the residual effect of the heartbeat. Although the amplitudes of the ripples are small, they introduce noise when attempting to detect echo shift due to temperature changes. Therefore, it is crucial to appropriately set the time difference between paired images when acquiring UVC images. By doing so, we can mitigate the impact of heartbeat-related ripples and enhance the accuracy of echo shift detection caused by temperature changes.

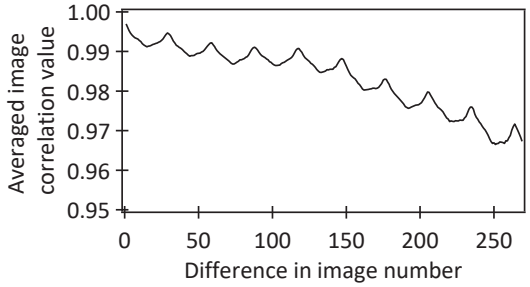

Fig. 3. Variation of averaged image correlation values as a function of the difference in image number between paired images.

Fig. 4 shows the following forearm images: (a) a UVC image before the initiation of warming, (b) a UVC image captured between 2 to 11 seconds after the onset of warming, (c) a UVC image captured between 25 to 34 seconds after the onset of warming, and (d) a UVC image obtained after the completion of warming. When depicting these UVC images, the difference in image numbers was set to 65 in order to suppress the effect of the heartbeat and to show the effect of temperature change with high sensitivity.

The result depicted in (a) before the initiation of warming represents the noise level attributed to the heartbeat. In the UVC images (b, c) captured during warming, a significant increase in blue contrast is observed in the region near the skin surface, while the deeper region exhibits a more pronounced red contrast compared to (a). These contrasting patterns are interpreted as corresponding to the subcutaneous fat region (approximately 3 mm thick) and the underlying muscle tissue region, respectively. Furthermore, upon comparing (b) and (c), it becomes evident that the contrast is lower in (b). This discrepancy can be attributed to the rapid temperature change not yet affecting the muscle layer at an earlier time, as it is influenced by the absorption of ultrasonic waves in the subcutaneous fat. Therefore, (c), which was generated using echo data obtained some time after the start of warming, proves to be an effective UVC image that successfully highlights the distinct contrast between the subcutaneous fat region and the underlying muscle tissue. The temperature increase within the muscle tissue area is estimated to be approximately 0.05 °C s^{-1}. In (d), obtained after the completion of warming, a notable transition occurs within the subcutaneous fat region, shifting from blue to red, while the majority of the muscle tissue region undergoes a shift from red to blue. These changes are reasonable outcomes that correspond to variations in ultrasonic velocity within their respective regions as the temperature decreases. Therefore, the results depicted in Fig. 4(b-d) can be deemed valid UVC images.

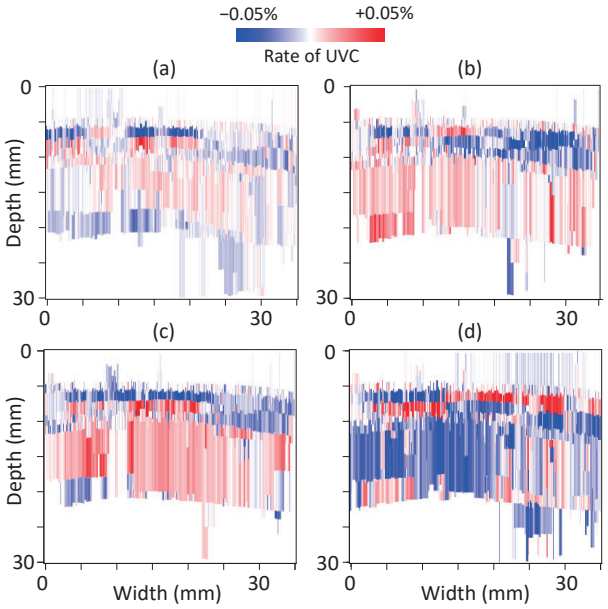

Fig. 4. UVC images of the human forearm: (a) before warming, (b, c) during warming, and (d) after warming.

4. Conclusion

The UVC method was applied to the human forearm. Through a comparison of UVC images before, during, and after warming, where the effect of the heartbeat was effectively suppressed, we observed clear and effective depictions of the subcutaneous fat and muscle areas.

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

References

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