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Basic Study on Frequency Characteristics in Reflected Ultrasound Signal of Lower Limb Edema Using FDTD Method

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1. Introduction

Edema[1] is the accumulation of water in the interstitium of tissues in the body. Edema has a tendency to occur in the lower limb the influence of gravity. It is also classified as a temporary or chronic condition. Early detection is desirable because the latter often leads to serious conditions such as heart and kidney failure. Quantitative diagnosis of early onset of chronic edema leads to disease detection. Currently, the indentation test is the most common method of testing for edema. It is a method of measuring the recovery time of the indentation created by applying acupressure to the affected area. The indentation test is difficult to diagnose the initial onset of chronic edema. Another problem is that the results differ from one diagnostician to another due to the lack of standardization. Therefore, quantitative diagnosis of lower limb edema using ultrasound has been investigated[2-3]. In a previous study, skin thickness of the lower limb was measured using ultrasound[4-6]. However, we were faced with the problem of skin thickening in fatty lower limb, even in cases without edema. Hence, we focused our attention on tissue changes caused by edema. The reflected ultrasound signal varies with changes in the tissue. We evaluated the changes in reflected ultrasound signal from their frequency characteristics[7]. In previous studies, measurements were made at a single frequency. In this paper, investigated the effect of the transmission frequency on the reflected ultrasound signal of the lower limb edema. So, we created the lower limb edema model using B-mode images. We simulated the propagation of lower limb edema using the finite difference time domain (FDTD) method[8]. We analyzed frequency characteristics of ultrasound reflection signals at the sound-receiving points in the model using the Fast Fourier Transform (FFT) method.

2. Binarization Model

We constructed an analytical model using B-mode images of the lower limb. We prepared edema-positive and edema-negative lower limbs. Lower limbs were classified according to the recovery time of the physician's indentation test. The lower limb with a recovery time of 15 seconds or longer was classified as edema-positive. The Lower limb with a recovery time of fewer than 15 seconds was classified as edema-negative. We recorded B-mode images of each lower limb using an ultrasound machine (Canon Viamo SV7). The measurement point was the front surface of the tibia. We converted the B-mode image into a 256-level grayscale image. Then, we removed the skin surface (20 px depth) containing acoustic artifacts in the B-mode images. The spatial resolution of the B-mode image was 39 μm. When applied to the FDTD method, the spatial resolution had to be reduced to 10 μm. We, therefore, used nearest neighbor interpolation to satisfy the condition.

In this analysis, we simulated ultrasound propagation from skin to bone. To achieve this, we cropped B-mode images below the bone. We binarized the cropped B-mode image and separated it into water and fat. The threshold value for binarization was set to the mean value of the Gaussian distribution when the amplitude characteristics of the B-mode image were approximated by a Gaussian distribution. The report by Pragasam et al[2] indicated that the hypoechoic component contained water. We thus defined water as below threshold and fat as above threshold. Based on this, the B-mode image was incorporated into the analysis model for the FDTD method. We inserted a 1 mm thick skin at the top of the analytical model. In addition, we inserted bone at the bottom of the model.

3. Analysis Method

We calculated ultrasound waveforms in two-dimensional space using the FDTD method, which is a time-domain sound wave propagation analysis method. The spatial discrete width was 10 μm. The temporal discrete width was 1 ns. The sound field was 7×7 mm. The absorption boundary was implemented on the outer edge of the sound field with absorption boundary of Mur[9]. The sound source was a line source consisting of point sources arranged in the x-axis direction. In addition, the sound source was a three-wave sine wave. Simulations were performed from frequencies 1, 2, and 5 MHz. **Table 1** shows the parameters of the medium used in this simulation[10-11]. Attenuation of Sound field is used by Eq. (1). Where P is the sound pressure, P_0 is the past sound pressure, α is the

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attenuation coefficient, and x is the distance. Attenuation coefficient α was used 0.05 Np/mm.

$$P = P_0 e^{-2\alpha x} \tag{1}$$

The B-mode image was scanned in the x-axis direction. The sound-receiving points were placed at each of the three divided positions of the sound field. We analyzed frequency of the time waveforms at each the sound-receiving points using the FFT method. The FFT method used a sampling frequency of 50 MHz and a Hanning window as the window function.

Table 1 Medium parameters.

Medium	Speed of Sound m/s	Acoustic Impedance MPa・s/m
Water	1522	1.51
Fat	1465	1.44
Skin	1450	1.35
Bone	3635	6.98

4. Analysis Result

We calculated the ratio of water to fat in the binarization model. Fat and water of edema-positive model were 25.8 % and 40.4 %, respectively. Fat and water of edema-negative model were 25.8 % and 40.4 %, respectively. The edema-positive model increased percentage of water compared to the edema-negative model. This result depends on the threshold of binarization and should be investigated in further samples.

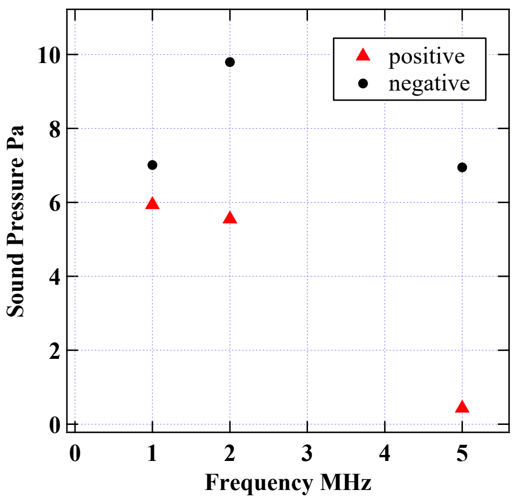

Fig. 1 Peak value of transmit frequency.

The frequency characteristics of the ultrasound reflection signal were analyzed using B-mode images of edema positive and negative. **Figure 1** shows the average of the peak values of the transmitted frequency at each sound-receiving points. Sound pressure decreased with increasing frequency with and without edema. We calculated the peak value difference between edema positive and negative in **Fig. 1**. The peak value difference ΔP_{1MHz} at a transmission frequency of 1 MHz was 0.52 Pa. The peak value difference ΔP_{2MHz} and ΔP_{5MHz} were 2.6 Pa and 3.0 Pa, respectively. The difference in peak values widened as the frequency increased. The development of edema causes tissue structure heterogeneity by fibrosis of soft tissues. Ultrasound attenuation increases when propagating through an inhomogeneous medium. This property may account for the decreased peak edema-positive value.

5. Conclusion

In this study, the lower limb edema model was created using B-mode images. We analyzed frequency using the ultrasound reflection signal of the model. The frequency characteristics showed that there was a difference in the peak value of the transmitted frequency between edema positive and negative. The present analysis was performed with and without edema. Further study is needed to determine if there is a correlation with edema progression.

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