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High Frequency Ultrasound Measurement of Micro Displacement in Human Skin Induced by Arterial Pulsation

拍動によりヒト皮膚に生じた微小変位の高周波数超音波計測

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1. Introduction

Mechanical property of the skin is one of the important factors for diagnosis of human skin diseases. Quantitative method of measuring skin elasticity is also desired in the cosmetic field.

Elastography[1-3] is a common technique that estimates a stiffness of tissue using ultrasound. However, the technique needs deformation of the tissue induced by compression, vibrators or pistons. In this paper, we proposed a novel method for estimation of elasticity the arterial pulsation as an intrinstic deformation. The induced displacement is measured by high frequency ultrasound, and the tissue strain is calculated from the displacements at several points. The elastcity of the *in vivo* human skin is evaluated based on the calculated parameters.

2. Method

2.1 High Frequency Ultrasound Measurements

A vinylidene fluoride and trifluoroethylene P(VDF-TrFE) transducer was used for imaging. The aperture diameter of the transducer was 2 mm, and the focal length was 4 mm. The central frequency of ultrasound was 100 MHz. The repetition rate was 2600 Hz. The sampling rate was 1 GS/s with 8 bit using a high-speed digitizer card (Acqiris DP 1400, Geneva, Switzerland). Four pulse echo sequences with 2000 sampling points were averaged at each line in order to increase the S/N ratio. The transducer was mounted on the scanner with the linear servo motors. The obtained RF signals of 200 scanning lines were converted to B-mode image by a conventional image processing algorithm of echography. The scan area was 2.0 mm wide and 1.5 mm deep. A subject was one healthy male volunteer (24 year-old) who didn't have significant skin diseases. The measured area was the skin in his forearm.

2.2 Elasticity Estimations using Pulsation

In this paper, we proposed elasticity estimation method using the arterial pulsation instead of compression, vibrators and pistons. Elasticity of human skin was estimated from deformation generated by the pulsation. A scan line for an M-mode image of the human skin was decided from the B-mode image. The scan depth was 1.0 mm, and the scan time was 1.1 sec. The displacement induced by arterial pulsation was micrometer orders. The induced displacements $u(z,t)$ were measured by the 1-D complex cross-correlation method along the depth z of the fixed scanned point at time t. The kernel size was 195 µm, and the overlap was 97.7 %.

A strain $s(z,t)$ was also calculated by differentiating the displacement with a depth z. Assuming that the direction of the induced displacement is along the depth, the displacement resulting from the arterial pulsation can be written as

$$\mathrm{u}(z,t) = u_0 \exp\{i(\omega_0 t - kz)\}, \quad (1)$$

where ω_0 and k are the angular frequency and the wavenumber, respectively. The temporal Fourier transform $\mathrm{U}(z,\omega)$ of the displacement (1) is obtained by the following equation

$$\mathrm{U}(z,\omega) = 2\pi\delta(\omega-\omega_0)\exp(-kz). \quad (2)$$

Substituting the angular frequency ω_0 of the measured displacement to the equation (2), the phase can be yielded by

$$\angle \mathrm{U}(z,\omega_0) = -k'z. \quad (3)$$

where k' is a real component of the wavenumber k. Computing the phase of the angular frequency ω_0 at each depth z, the real part of the wavenumber k' was estimated by using least-square method. The shear wave velocity Vs at the center frequency fc of the pulsation is obtained with

$$V_s = {2\pi f_c}/{k'}. \quad (4)$$

The center frequency fc was obtained by using temporal Fourier transform of the measured displacement. Assuming that Poisson's ratio is 0.5, the Young modulus E and the Shear modulus G are respectively obtained by

$$\mathrm{E} = 3\rho V_s^2 \quad (5)$$

and

$$G = \rho V_s^2, \qquad (6)$$

where ρ is the density of the skin tissue.

3. Result

3.1 Measured Displacements

Fig. 1 shows the B-mode image of the human skin. In the B-mode image, epidermis and dermis were clearly distinguished. The scan line for an M-mode was decided from the B-mode image (red line). Each layer was slightly pulsating. Fig. 2 shows the induced displacements at each depth. Displacements were observed periodically with the arterial pulsation at each depth. The frequency that had max power in the frequency domain was 0.63 Hz and the bandwidth was from 0.63 to 12.7 Hz.

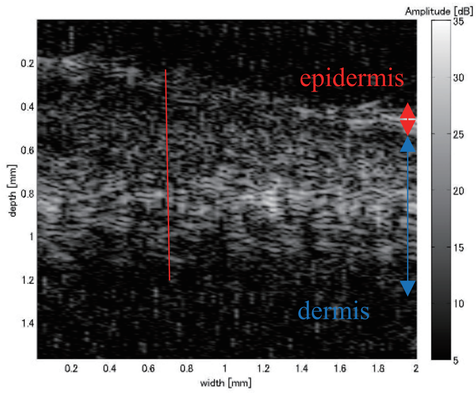

Fig. 1 B-mode image of human skin

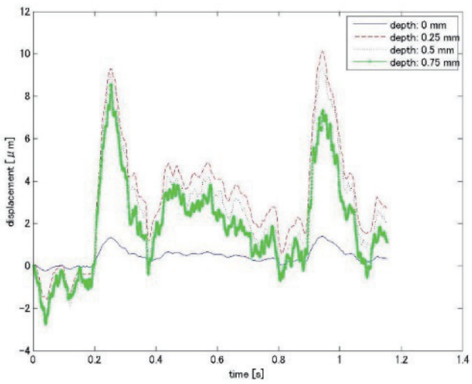

Fig. 2 displacements induced by pulsation

3.2 Estimated Elasticity

Fig. 3 shows the average strain obtained by differentiating the displacement with depth z at the moment when the displacement showed maximum value. The error bars show the standard deviation of the calculated strain from 0.34 to 0.38 ms. The thickness of the epidermis and dermis was decided from B-mode image. The average shear wave velocity Vs through the skin was 0.44 ± 0.15 m/s at the bandwidth. The average Young modulus E and the average Shear modulus G were 0.81 ± 0.47 kPa and 0.27 ± 0.16 kPa, respectively.

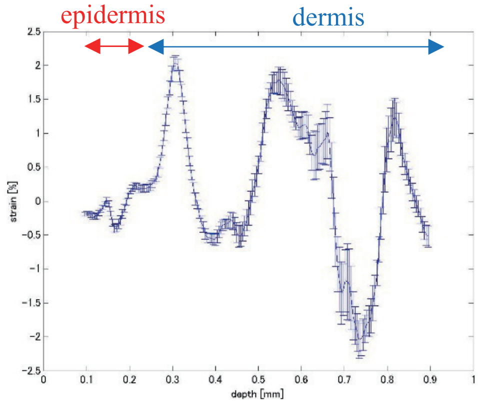

Fig. 3 the calculated strain

4. Discussion

The strain of the epidermis was lower than that of the dermis. The shear wave velocity was 0.44 ± 0.15 m/s, and was in good agreement with the past report[4]. The Young modulus and the Shear modulus of the skin at low frequency were estimated, but a hypothesis that the skin was a soft tissue didn't work out according to the past researches. So, we need to discuss about this issue.

5. Conclusion

The displacements induced by arterial pulsation were measured with high frequency ultrasound. The strain, the shear wave velocity, the Young modulus and the Shear modulus were estimated from the measured displacements. These estimated parameters well conformed to the histology of the skin and the past reports. We believe this proposed method is very useful to evaluate the elasticity of the human skin.

References

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