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# Group Comparison of Luminal Surface Roughness of Human Carotid Artery Estimated by Ultrasound Micro-Displacement Measurement

超音波微小変位計測によるヒト頸動脈内腔の表面粗さの群間比較

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## 1. Introduction

Several studies have reported that the internal elastic layer and endothelial cells are damaged in the early stage of atherosclerosis[1]. This finding indicates that, the luminal surface of the artery will become rough as atherosclerosis progresses. Therefore, it would be useful to measure such minute roughness on luminal surface of the artery for diagnosis of early stage atherosclerosis. The luminal surface on the artery is covered with endothelial cells, and thickness of an endothelial cell is 10-20 μm[2]. Since the spatial resolution of B-mode ultrasound image depends on the ultrasound wavelength, the axial resolution of a conventional ultrasonographic device is about 150 μm, and the device cannot detects the irregularity of the luminal surface. Our group has reported, a high spatial resolution imaging method of the surface roughness with micron order using the movement of artery caused by a cardiac output[4]. In the present study, we apply the method to human carotid arteries of two age groups, and investigate the difference of irregularity between the groups estimated by the method.

## 2. Materials and Methods

The proposed method measures the axial displacement of the arterial wall between two adjacent axial measurement lines. When the tissue structure in front of the arterial wall is identical between the two measurement lines, that is, the two measurement lines have the same path length, the axial displacements of the surface of the arterial posterior wall between ($n$-1)-th frame and $n$-th frame along $m$-th ultrasound beam $\Delta d(m,n)$ is estimated by the phase shift of the center frequency of the ultrasound RF data (phased-tracking method[3]) as follows:

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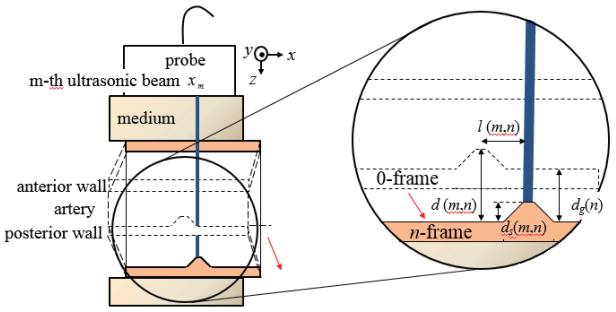


Fig. 1. Diagram of displacements of the arterial wall and measuring axial displacements.

$$\Delta\hat{d}(m,n) = \frac{c}{2\omega_0}\Delta\theta(m,n) \qquad (1)$$

where, $c$ is the sound velocity in a medium inside the tissue. To eliminate the path-length difference between two measurement lines, we use the movement of the carotid artery. Since the carotid artery moves in the lateral direction, the lateral position measured by a scan line in the previous frame, where there should be no variation of path length between two adjacent frames. When the pulse wave arrives, the arterial diameter increase and the artery moves to heart direction because aortic arch is pulled due to heart muscle contraction[4]. Therefore, we measure without moving ultrasound probe, and eliminate the measurement error.

The axial displacement between 0-th frame and $n$-th frame $d(m,n)$ is summation $\Delta d(m,n)$ from the first frame to $n$-th frame. Now, axial displacement $d(m,n)$ comprehend displacement of arterial expansion $d_g(n)$ and the arterial surface $d_s(m,n)$. Assuming the displacement of arterial expansion is constant with beam position due to long wavelength, displacement of arterial expansion is estimated as follow:

$$d_g(n) = \frac{1}{M}\sum_{m=0}^{M-1} d(m,n). \qquad (2)$$

Therefore, we can get displacement of surface roughness $d_s(m,n)$ subtracting displacement of arterial expansion $d_g(n)$ from whole axial displacement $d(m,n)$.

On the other hand, we estimated the lateral displacement $l(m,n)$ of the arterial wall at the *m*-th ultrasound beam between 0-th and *n*-th frame, using the block matching. Therefore, we determine the point at the intersection of arterial wall by the *m*-th ultrasound beam with lateral position of the arterial wall at the *n*-th frame.

The measured surface profile by ultrasound convolved the point spread function (PSF) of the ultrasonic diagnostic equipment. Therefore, we design a filter based on the Wiener filter in frequency domain to suppress the influence of PSF. We obtain enhanced surface profile $f(x)$ by the inverse Fourier transformation.

Since the damaged endothelial cells appear in the early stage of atherosclerosis, we expect that the aging also influences the phenomenon. Therefore, we prepare two group; the age of one group ranges from 20 to 30 years, and the other ranges from 50 to 60 years. We use Hitachi Aloka Medical ProSound F75 with a linear array probe with center frequency of 7.5 MHz. We also measure the cardiac cycle using electrocardiogram. We calculate difference between surface profile and average of surface profile $\bar{f}(x)$. In this study, we employ a weighted moving average of surface profile to take into account arterial shape. The fluctuation $f_s$ is given by

$$f_s = \sqrt{\frac{1}{n}\sum_{x=0}^{n-1}\left(f(x)-\bar{f}(x)\right)^2} \qquad (3)$$

## 3. *In vivo* Experimental Results

We measured the carotid artery of three healthy subjects; two for the younger group and one for the older group. **Figure 2** shows the ultrasound B-mode image of carotid arterial posterior walls. Since a conventional B-mode imaging has an average spatial resolution, it is very difficult to acquire the information of the luminal surface profile on the artery. **Figure 3** shows the arterial posterior surface profile obtained by proposed method. We obtain the fluctuation $f_s$ from the surface profile. We moved 80 points for moving average. In young group, the fluctuation was 0.99 μm and 0.90 μm. In contrast, at the fluctuation of older subject was 1.51 μm. This result shows that an older subject group has a high fluctuation compared with those of younger subjects.

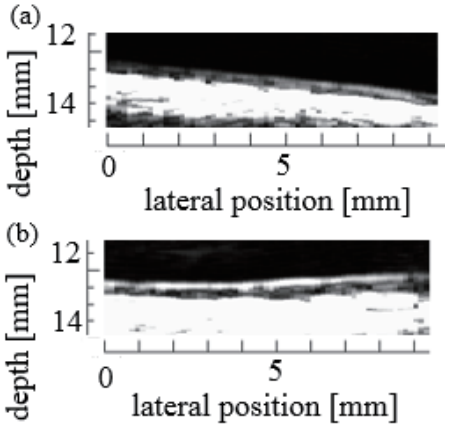


Fig. 2. B-mode ultrasound image of carotid posterior artery acquired from a healthy subject, (a) from younger group, (b) from older group.

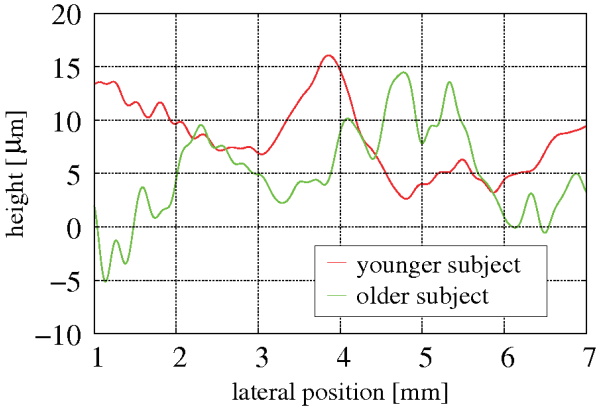


Fig. 3. The estimated luminal surface profile of carotid posterior artery (from subject of younger group in red, from subject of older group in green).

## 4. Conclusion

In this study, we compared two subjects to evaluate validity of this method. Comparing two arterial surface profiles estimated by the proposed method, an older subject had high fluctuation compared with those of younger subjects. Future work should include the addition of subject, especially older subjects.

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