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Removal of Displacement Caused by Arriving of Pressure Wave for Accurate Estimation of Surface Roughness of Arterial Wall Using Ultrasonic RF Echo

超音波RFエコーによる頸動脈壁の表面粗さ高度推定のための拍動による変位の除去

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1. Introduction

Diagnosis of atherosclerosis in an early stage is important to prevent from cousing a stroke and heart attack. Our group have been trying to measure surface roughness of the arterial wall[1, 2]. In early stage of atherosclerosis, the luminal surface of an arterial wall becomes rough as a result of endothelial damage[3]. It would be useful to measure minute surface roughness of the carotid arterial wall for early diagnosis of atherosclerosis. For this purpose, sub-micron resolution is required because endothelial cells are 1-10 μm thick[4]. Consequently, conventional modalities (MRI, CT, US, PET) cannot measure such roughness due to their spatial resolution over 100 μm.

The goal of this study is to estimate surface roughness of the carotid arterial wall with sub-micron spatial resolution. During a cardiac cycle, the carotid arterial wall moves not only in the radial (=axial) direction but also in the longitudinal (=lateral) direction[5]. This langitudinal movement induces the axial displacement (change in height during longitudinal movement) of the surface st sn ultrasonic beam when the surface is rough. We can measure this axial displacement with a sub-micron resolution[6]. Simultaneously, we identified the lateal positions, where the axial displacements were measured, to obtain the surface profile by combining these two measurements. However, the measured axial displacement contains the displacement caused by global wall motion due to heartbeat in addition to the displacement caused by surface roughness. It is necessary to remove displacement caused by global wall motion for estimation of minute surface roughness of the arterial wall.

2. Method

During cardiac systole, the vascular diameter is dilated due to an increase of internal pressure at the arrival of the pulse wave (**Fig. 1**). Radial (axial)displacement caused by this dilation is about 300-400 μm. Therefore, we have to remove this displacement to estimate minute surface roughness (1-10 μm).

As shown in Figs. 1(a) and 1(b), we define the k-axis and r-axis in the directions parallel and perpendicular to the arterial wall, respectively. Also, k-axis and r-axis in the directions parallel to x-axis and z-axis, respectively. In addition, we define reference position r = 0 at the surface of arterial wall on the r-axis. Lateral position of the m-th ultrasonic beam is denoted by x_m.

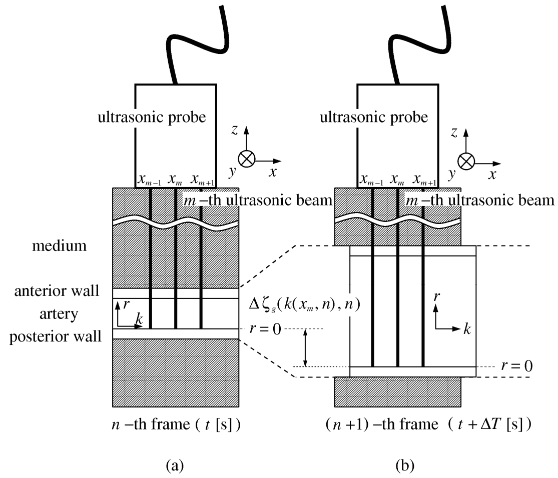

Fig. 1 Illustration of principle of measurement. (a) n-th frame (t [s]). (b) (n +1)-th frame (t +ΔT [s]).

As shown Fig. 1, in a region of a few hundred μm (x-axis), axial displacements $\Delta\zeta_g(k(x_i, n), n)$ between n-th frame and (n+1)-th frame at some positions x_i (i.e. i-th ultrasonic beams positions) ($i = 0, \pm 1, \cdots, \pm M$) are same because the wave length of pulse wave is about 10 cm (at 50 Hz). The displacements $\Delta\zeta_g(k(x_i, n), n)$ could be described as:

$$\Delta\zeta_g(k(x_i, n), n) = \Delta\zeta_g(n), \ (i = 0, \pm 1, \cdots, \pm M) \quad (1)$$

where $\Delta\zeta_g(n)$ is constant, M means the number

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of ultrasonic beams. By assuming that the mean of the axial displacements caused by surface roughness is zero, the global displacement $\Delta\hat{\zeta}_g(n)$ is calculated from the mean of the measured axial displacements $\Delta\zeta(k(x_i, n), n)$ as:

$$\Delta\hat{\zeta}_g(n) = \frac{1}{2M+1}\sum_{i=m-M}^{m+M}\Delta\zeta(k(x_i, n), n), \quad (2)$$

where $(2M+1)$ is the number of ultrasonic beams in a small region. Then, this mean displacement $\Delta\hat{\zeta}_g(n)$ is removed from original axial displacement $\Delta\zeta(k(x_m, n), n)$ for estimation of minute surface roughness.

In a basic experiment, we used a silicone phantom, which had a convex shape on its surface. **Fig. 2** shows the result of surface roughness of the phantom measured by a laser profilometer. As shown Fig. 2, the height and half-value width were estimated to be 15 μm and 440 μm, respectively. Also, a phantom was moved in the radial direction using automatic stage to simulate global wall motion.

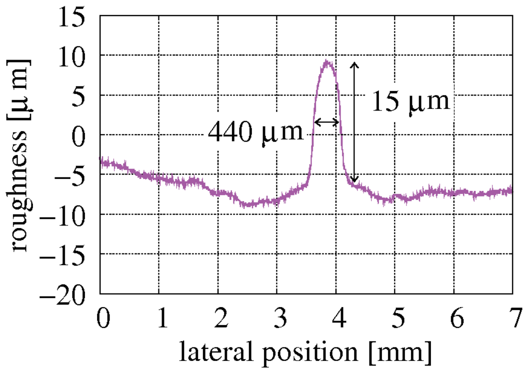

Fig. 2 Surface profile measured by laser profilometer.

3. Result

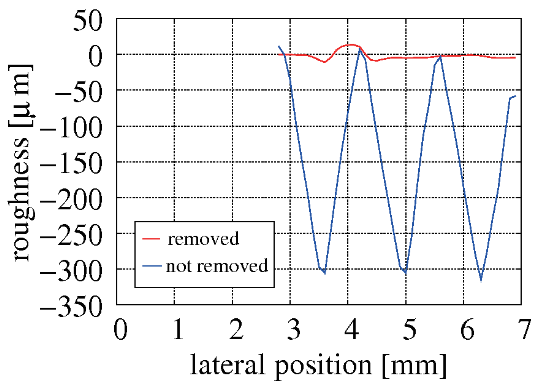

Fig. 3 Estimated surface roughness after removal of displacement caused by arriving of pressure wave (red line: removed, blue line: not removed).

Figure 3 shows surface roughness obtained by removed the global displacement caused by arriving of pressure wave (the red line). The blue line shows surface roughness obtained without removing the global displacement. As shown in fig. 2, a minute surface roughness could be detected by removing a large global displacement.

Figure 4 shows the enlarged estimate surface roughness obtained by removing the global displacement caused by arriving of pressure wave (the red line in Fig. 3).

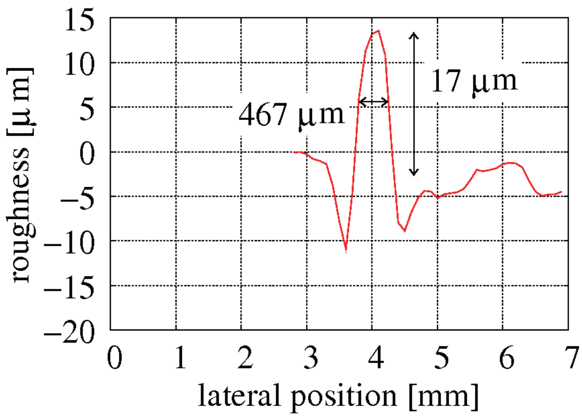

Fig. 4 Enlarged surface roughness obtained by removing global displacement caused by arriving of pressure wave.

The height and half-value width of the estimated surface profile were estimated to be 17 μm and 467 μm, respectively. These results showed that we could estimate the surface roughness of a phantom.

4. Conclusion

In this study, we could estimate minute surface roughness of the phantom moving in the axial and lateral directions in the basic experiment. Further investigation will be conducted to measure surface roughness of the arterial wall *in vivo*.

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