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# Analysis of blood echo signal using 18 MHz linear probe during flow mediated dilation

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## 1. Introduction

One of the useful methods for the early detection of atherosclerosis is the flow mediated dilation (FMD) to evaluate vascular endothelial function [1]. This method measures the amount of vasodilator substance, e.g., nitric oxide, produced by the increase in wall shear stress during reperfusion of the forearm after 3–5 mins of avascularization. However, a misalignment of a measurement position is a limiation for characterizing the change of the vessel diameter (several 7%) through the protocol. In addition to the vessel diameter, quantitative features such as flow velocity and shear rate are important to compare their temporal change between at rest and after avascularization.

A high-frequency linear array transducer has been developed to visualize superficial tissue structures [2]. This study explores the feasibility of the FMD by direct high-frame-rate blood flow imaging robust to disturbance. In this report, we have newly examined the visualization of superficial forearm artery using a 18 MHz linear array transducer, and estimated the quantitative features such as velocity, shear rate, and wall displacement in *in vivo* measurement.

## 2. Materials and Methods

### 2.1 Data acquisition

A linear array transducer (L18, 10–30 MHz bandwidth at −20 dB, Vermon) with 128 channels (element pitch of 0.1 mm) and a research-platform scanner (RSYS0016, Microsonic) were used to obtain the radio-frequency (RF) channel data (sampling frequency of 62.5 MHz). A center frequency of the excitation burst wave was 15 MHz. Multiple plane waves at 5 angles of −5, −2.5, 0, 2.5, and 5 degrees were transmitted at a pulse repetition interval of 96 µs, and coherently compounded. Total 2400 frames (for 1.15 s) were acquired in *in vivo* measurement. Transmitted plane waves were apodized by a Tukey function with a coefficient of 0.4. The elevation focus was 8 mm.

### 2.2 Data Processing

First, bandpass filters (10–22 MHz) with a 32-tap finite impulse response were applied to the RF channel data to suppress out-of-band components.

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The delay-and-sum beamforming with the dynamic aperture (F-number of 1) was applied to the filtered RF channel data. The beamformed RF data [matrix of lateral 12.8 mm × axial 11.0 mm (from 2 to 13 mm depth), 256 × 893 pixels] was reconstructed on a pixel-by-pixel basis (pitch of lateral 50 µm × axial 12 µm) at a sound speed of 1540 m/s. The coherently compounded RF data were used for the subsequent analysis.

A spatiotemporal filter based on the singular value decomposition was applied to the beamformed RF data to emphasize the blood flow signal. The low- and high-rank thresholds of the singular value for discriminating clutter components from blood flow components were empirically set at −56 and −78 dB, respectively, in reference to the power curve of the singular values.

### 2.3 Transmission and reception sound field

Basic features of the transmission and reception sound fields along the axial direction were evaluated by a stainless wire target (30 µm diameter) measurement in the degassed water at 25 °C. The maximum amplitude and full width of half maximum (FWHM) were calculated in the wire target at each axial position.

**Fig. 1** shows the maximum amplitude envelope and FWHM of the wire target in each axial position. A peak position of the amplitude envelope was equivalent to the elevation focus (8 mm), and its half range was preserved from 4 to 20 mm. The FWHMs of the axial and lateral directions were almost constant from 0.16 to 0.17 mm and from 0.23 to 0.30 mm, respectively. Hence, it is assumed that a stable measurement can be applied in the range of the forearm artery if the penetration depth is preserved.

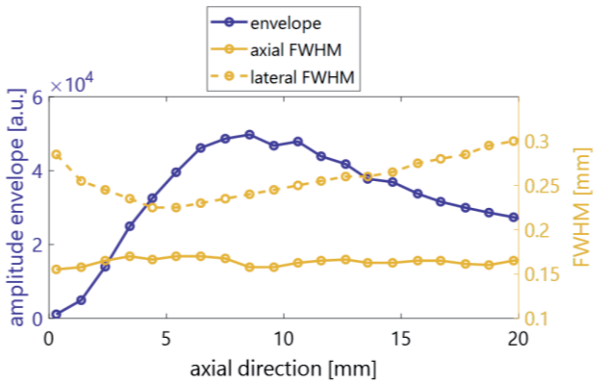


Fig. 1 Transmission and reception sound field along the axial direction.

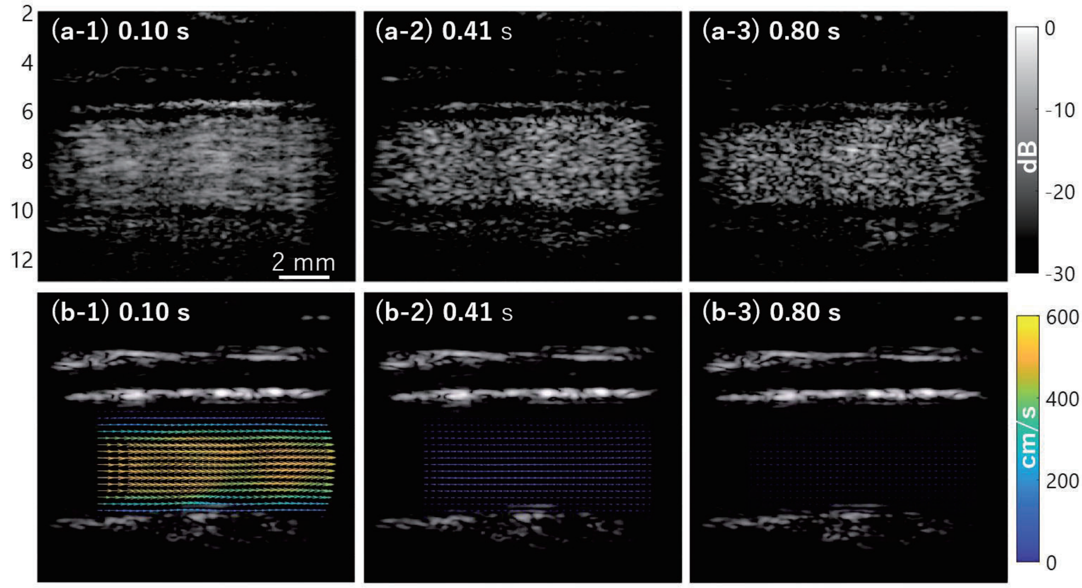


Fig. 2 Clutter-filtered high-frame-rate images of forearm artery. (a) and (b) B-mode and vector flow images at typical time (1)-(3).

### 2.4 *In vivo* analysis

This study was approved by the Ethics Committee of the University of Toyama under Approval No. 27-150. The forearm artery of a healthy subject was scanned at rest along the long axis under fixing the linear probe.

The flow velocity was calculated using a in-house block matching method [3]. The input of the block matching analysis was the amplitude envelope of the coherently compounded beamformed signals. The amplitude envelope was decimated with a factor of 2 in the axial direction. The block size was 60 × 60 pixels (1.4 × 3.0 $mm^2$ in the axial and lateral directions), and the search distance in both the directions was 20 pixels. Secondly, the gradient of the flow velocity profile along the axial direction was calculated as the shear rate in the neighborhood around the near- and far-wall boundaries. The wall displacement was also traced in the position of the maximum amplitude envelope at each raster from 3.0 to 9.8 mm.

## 3. Results

**Fig. 2** displays the clutter-filtered B-mode (a) and corresponding vector flow (b) images at the typical time of systolic (1) and diastolic (2)-(3) phases. The blood flow echo could be visualized with speckle pattern. The vector velocity was distributed as a parabolic profile. To compare the temporal fluctuation of quantitative features, **Fig. 3** plots the time evolution of the flow velocity, shear rate, and wall displacement. The wall displacement increased from 4.7 to 4.8 mm in the acceleration phase of the flow velocity and shear rate, and decreased in the following phase.

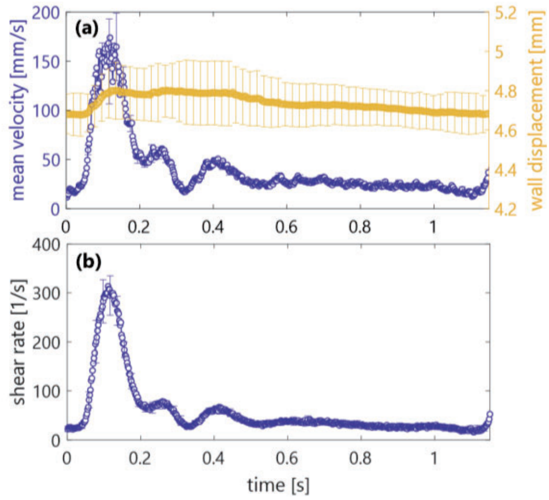


Fig. 3 Temporal fluctuation of mean velocity and wall displacement (a), and shear rate (b).

## 4. Conclusion

This study introduced visualization of the superficial forearm artery using the 18 MHz linear array transducer, and the quantitative functional parameters were estimated through the *in vivo* measurements. This exploration could contribute to refining the FMD technique and understanding the interaction of vascular remodeling. Further examination will be performed in and after avascularization.

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