High Frame Rate Ultrasonic Imaging of Artery-Wall Strain and Blood Flow

Hideyuki HASEGAWA[*,**] and Hiroshi KANAI[**,*]

* Department of Biomedical Engineering, Graduate School of Biomedical Engineering, Tohoku University, 6-6-05 Aramaki-aza-Aoba, Aoba, Sendai 980-8579, Japan
E-mail: hasegawa@ecei.tohoku.ac.jp

* Department of Electronic Engineering, Graduate School of Engineering, Tohoku University, 6-6-05 Aramaki-aza-Aoba, Aoba, Sendai 980-8579, Japan
E-mail: hkanai@ecei.tohoku.ac.jp

Abstract

Blood flow measurement is an important practical routine in diagnosis of atherosclerosis. In addition, mechanical properties of arterial walls affected by atherosclerosis are significantly different from those of normal arteries, and various studies have been conducted to measure the artery-wall elasticity (strain). It would be useful if the strain and blood flow could be assessed simultaneously because plaque vulnerability is closely related to its mechanical property and the shear stress from blood flow. In this study, high frame rate (3500 Hz) acquisitions of ultrasonic echoes required for simultaneous measurement of blood flow and artery-wall strain were achieved by parallel beam forming. In *in vivo* measurement of a carotid artery, power of echoes from blood particles was successfully imaged together with the artery-wall strain. This method would be useful for diagnosis of atherosclerosis, such like plaque vulnerability.

Key words: Artery-wall strain, Blood flow, Ultrasound, Parallel beam forming, High frame rate, Atherosclerosis

1. Introduction

Mechanical properties of the arterial walls are significantly changed by atherosclerosis, and various studies have been recently conducted to measure the regional elastic properties (radial strain) of the arterial wall. We have developed a phase-sensitive correlation-based method to measure the regional radial strain [(1)]. On the other hand, the measurement of blood flow is an important practical routine in the diagnosis of atherosclerosis. It would be useful if the regional strain of the arterial wall and blood flow could be assessed simultaneously. Such measurement requires a high frame rate of several kilohertz. In this study, high frame rate acquisitions of ultrasonic RF echoes (about 3500 Hz) were achieved using parallel beam forming [(2)] to realize a simultaneous imaging of the artery-wall strain and blood flow.

2. Methods

In conventional linear scanning, both transmitting and receiving beams are focused along the same scan line. Therefore, the frame rate, f_{FR}, is determined by dividing the pulse repetition frequency (PRF), f_{PRF}, by the number of beams, N_{bm}. For example, frame rate f_{FR} is about 140 Hz when f_{PRF} = 10000 Hz and N_{bm} = 72.

In this study, a plane wave was transmitted using N_t = 96 elements of a linear array probe equipped to a commercial diagnostic system, and RF echoes were received by the same 96 elements [(3)]. One receiving beam was formed using the RF signals received by N_e = 72 of the 96 elements. Therefore, $(N_t - N_e)$ = 24 receiving beams could be formed for each transmission. In the present study, the number of transmissions, N_{tr}, was set at 3, and by performing receive beam forming for each of the three transmissions, $(N_t - N_e)$ x N_{tr} = 72 receiving beams were created. Pulse repetition frequency f_{PRF} was set at 10416 Hz (observable depth: 74 mm) and, thus, a frame rate f_{FR} of 3472 Hz was achieved.

In this study, the arterial wall was scanned along its longitudinal direction using a linear array probe so that all the receiving beam created at a steering angle, θ, of 0 degrees coincided with the arterial radial direction. Therefore, receiving beams at θ = 0 degrees were formed to estimate the radial strain of the arterial wall using our method [2]. For imaging of blood flow based on the method used for the conventional power Doppler imaging, receiving beams at θ = -5 and +5 degrees were formed. RF signals obtained by the above procedure were used for estimation of the radial strain and blood flow and the results were combined to create an image.

3. Results

The right common carotid artery of a 33-year-old male was measured *in vivo*. Envelope signals of RF echoes obtained by beam forming at θ = 0 degrees were detected to create conventional B-mode images.

RF signals obtained by oblique beam forming at θ = -5 and +5 degrees were enhanced by high-pass filtration based on the standard double delay line canceller. The average power of the high-pass filtered signals was combined with the envelope signals obtained by beams at θ = 0 degrees.

Figures 1(a) and 1(b) show ultrasonic images at the time of the R-wave of electrocardiogram and 0.15 s after the R-wave. As shown in Fig. 1(b), echoes from blood particles are enhanced when the blood flow velocity is high (at 0.15 s), and the artery-wall strain was overlaid using the color code shown in Fig. 1(b). This result shows that the proposed method successfully imaged the artery-wall strain and blood flow simultaneously.

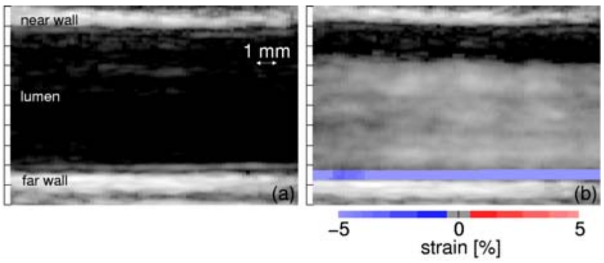

Figure 1: Ultrasonic images of a carotid artery of a 33-year-old male obtained at (a) the time of R-wave of electrocardiogram and (b) 0.15 s after R-wave.

4. Conclusion

In this study, a high frame rate acquisition of RF echoes (3472 Hz) was achieved to realize simultaneous imaging of the artery-wall strain and blood flow. Such method would provide useful information for diagnosis of atherosclerosis.

References

(1) Hasegawa H. and Kanai H., Reduction of Influence of Variation in Center Frequencies of RF Echoes on Estimation of Artery-Wall Strain, IEEE Trans. Ultrason. Ferroelect. Freq. Contr., Vol. 55, No. 9 (2008), pp. 1921-1934.

(2) Tanter M., Bercoff J., Sandrin L., and Fink M., Ultrafast Compound Imaging for 2-D Motion Vector Estimation: Application to Transient Elastography, IEEE Trans. Ultrason. Ferroelect. Freq. Contr., Vol. 49, No. 10 (2002), pp. 1363-1374.

(3) Hasegawa H. and Kanai H., Simultaneous Imaging of Artery-Wall Strain and Blood Flow by High Frame Rate Acquisition of RF Signals, IEEE Trans. Ultrason. Ferroelect. Freq. Contr., Vol. 55, No. 12 (2008), pp. 2626-2639.