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Deduction of two-dimensional blood flow vector by dual angle diverging waves from a cardiac sector probe

セクタプローブからの二方向拡散波による二次元血流ベクトルの導出

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1. Introduction

Cardiovascular disease is the most common cause of death in the world[1]. Blood flow measurement is essential to diagnose the severity of valvular regurgitation or stenosis. Further, quantitative flow analysis in the left ventricle is important to predict the prognosis of the heart failure. In contrast to phase contrast magnetic resonance imaging which requires temporal and spatial averaging for flow visualization, color Doppler echocardiography non-invasively provides real-time information on blood flow. However, conventional color Doppler method merely provides blood flow along the ultrasonic beam.

In this study, we propose a method to deduce 2-D blood flow vector by dual angle diverging waves from a sector probe for the diagnosis of the heart.

2. Materials and Methods

2.1 Experimental setup

Diverging waves with two different angles were irradiated from the single probe. Two sets of 1-D velocity components were calculated from auto correlation method[2]. The 2-D velocity components were deduced based on a geometric relation of 1-D velocity components on two different angles as shown in **Fig.1**. Fig.1 shows the schematic illustration of transmissions of dual angle diverging waves. The 2-D velocity components could be calculated by

$$V_x = -\frac{v_1 \cos\theta_2 - v_2 \cos\theta_1}{\sin(\theta_1 - \theta_2)} \quad (1),$$

$$V_z = \frac{v_1 \sin\theta_2 - v_2 \sin\theta_1}{\sin(\theta_1 - \theta_2)} \quad (2),$$

where θ_1 and θ_2 were the angles of each 1-D velocity vector, respectively.

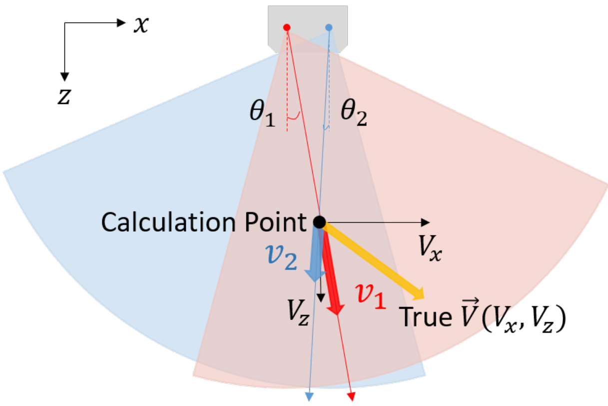

Fig.1 Schematic of transmissions of dual angle diverging waves

The sector array probe (Okusonic S69-010) with a central frequency of 2.5 MHz was used in the experiment. A programmable ultrasound imaging system (Verasonics Vantage 256 system) was used to acquire the ultrasound signals. The acquired RF signals were processed in Matlab software (MATLAB 2013a) offline. The acquisition sequence consisted of B-mode images and the Doppler measurements. First, the data for B-mode were obtained by 7 transmissions of different angles from -30 to +30 deg. with a step of 10 deg. After the transmissions, the data for the velocity estimation were obtained by 16 transmissions of the intersectional angled waves alternately (8 × 2, 30 deg. and -30 deg.). A frame rate of imaging was set to 100 fps.

2.2 Phantom and PIV measurement

A vortex flow was measured for validation of the proposed method. A cylinder phantom was made of a PVA (Polyvinyl Alcohol) gel. A blood phantom consisted of an aqueous solution mixed with glycerin. The 2-D velocity components were calculated from the acquired data by using the proposed method. Also, the vortex flow was measured by a high frame rate CCD camera with

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100 fps to calculate the 2-D velocity components by using PIV (Particle Image Velocimetry) method. The velocity vector calculated by the PIV method was compared with that by the proposal method. A schematic of the experiment system is shown in **Fig.2**

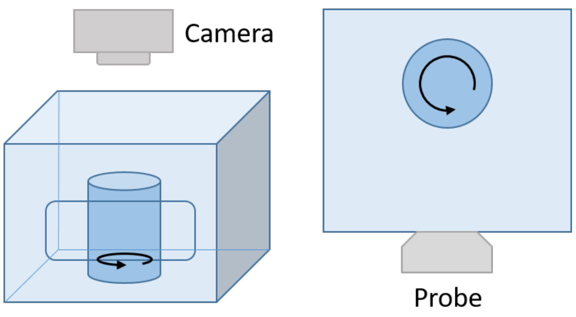

Fig.2 Schematic of experiment system

3. Result and Discussion

Fig.3 (a) shows the result of 2-D flow vector measured by the proposal method, and **Fig.3 (b)** shows the result calculated by the PIV method. The 50 frames of the velocity vector were averaged to correct time dispersions among frames. The directions estimated by the proposed method almost conformed to that by the PIV method. Ranges of velocity coincided because values below about 100 mm/s were calculated in almost all regions in both images. The velocity estimated by using the PIV method is slower in the region near the circumference, and relatively faster in the region at the center. On the other hand, a variance of the velocity estimated by the proposal method was very high. The velocity more than 100 mm/s were observed in the lower region of the vortex flow. The velocity estimated by the proposed method conformed to the velocity measured by the PIV method. A root mean square error (RMSE) of V_x and V_z were 31.7 mm/s and 11.4 mm/s, respectively. Hence, the errors of V_x was ascribable to the RMSE of the velocity estimated by proposal method. According to the equations (1) and (2), the measurement errors of the 1-D velocity led to the estimation errors of V_x because angles between each 1-D velocity vectors were too small.

4. Conclusion

In this study, the 2-D velocity vector estimated by using the dual angle diverging waves from the sector probe. The direction by the proposal method agreed with that by the PIV method. The accuracy of the estimation in the V_z components was sufficient for the measurements. On the other hand, the errors of the V_x components were insufficient. The results indicated that the details of the blood flow dynamics in the cardiac could be visualized by using proposed method.

References

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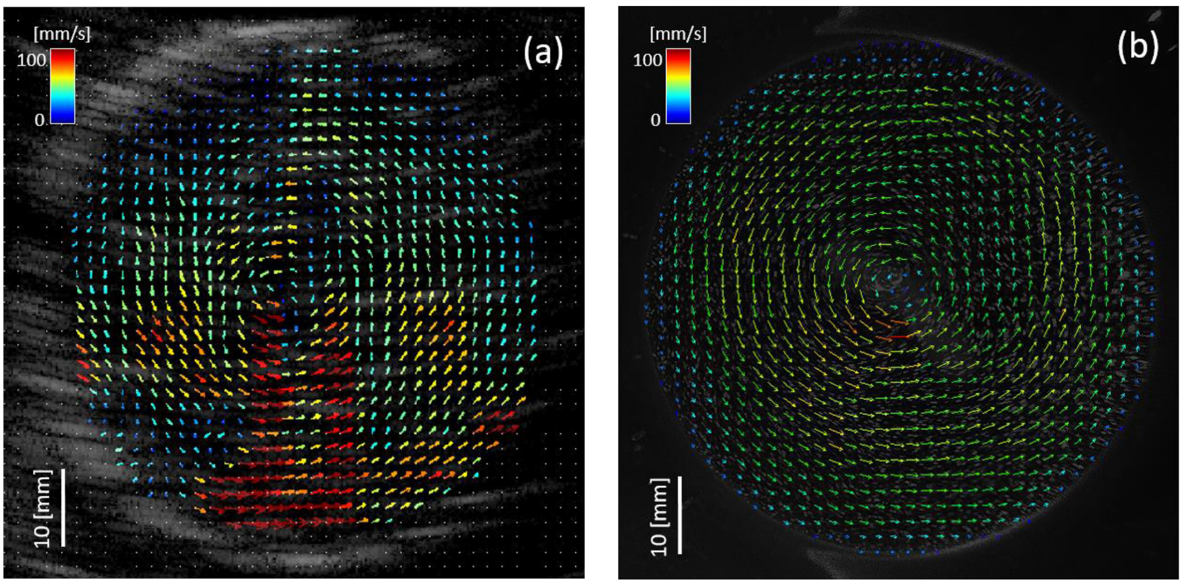

Fig.3 Results of 2-D flow vector measurement (a) by proposed method and (b) by PIV.