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Development of blood flow velocity estimation method from Doppler echocardiography and its validation by MRI data

超音波ドプラ法に基づく血流速度推定法の開発とMRIデータによる検証

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1. Introduction

Echo-Dynamography (EDG) [1] is a smart visualization technique in echocardiography in which two-dimensional (2D) distribution of blood flow vector in cardiovascular system is deduced by applying fluid dynamics theories into Doppler velocity datasets. Several validation studies of the method have been performed [2]. However, these simulation and modeling were too simple to reproduce unstable and asymmetrical flow in left ventricle (LV). Therefore, in the present study, performance of EDG *in vivo* is validated by comparing blood flow distribution obtained with PC-MRA (Phase Contrast Magnetic Resonance Angiography) and reconstructed blood flow vectors obtained by calculating virtual Doppler velocity acquired from various locations of virtual probe in accordance with EDG algorithm.

2. Validation methods

ECG-triggered and breath-hold PC-MRA sequences were obtained from one healthy volunteer. A commercially available 1.5T MRI apparatus (EXCELART Vantage MRT200-PP5, Toshiba Medical, Japan) was equipped for the MRA data acquisition. 2D PC-MRA method with velocity flow encoding of 100cm/s, TR of 24 msec, TE of 10msec, flip angle of 20 degree, slice thickness of 8 mm, matrix size of 128 (Read out direction) × 256 (Phase encoding direction) and resolution of 2.73mm × 1.37mm was used. Velocity fields during phases in which high velocity were shown in left ventricle (LV), such as ejection (E), reduced ejection (RE), early rapid filling (ERF), late rapid filling (LRF), and atrial contraction (AC) phase, were analyzed. Virtual Doppler velocity fields were acquired from various probe positions on the body surface in T2 weighted image (T2WI).

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In this study, virtual Doppler velocity is defined as the blood flow components on the radial direction in a polar coordinate system, simply directed to or away from virtual sector probe. Overall relative errors were calculated according to the following equation [3]:

$$E_{tot} = \frac{\int_\Omega \varepsilon(x,y)dS}{\int_\Omega \|\mathbf{V}_{\mathrm{MRI}}\|dS} \quad (1) \qquad \varepsilon(x,y) = \|\mathbf{V}_{\mathrm{MRI}} - \mathbf{V}_{\mathrm{EDG}}\| \quad (2)$$

where ε shows the pointwise error expressed as a function of the Cartesian coordinates (x, y), which was defined as the difference of the absolute values between $\mathbf{V_{MRI}}$ (velocity vectors measured by PC-MRA) and $\mathbf{V_{EDG}}$ (reconstructed velocity vectors obtained with virtual Doppler velocity in accordance with EDG method). Ω is the area of interest. In particular, note that analytical area was limited to LV and left atrium during filling phases when aortic valve is closed, and LV and ascending aorta during ejection phases when mitral valve is closed.

3. Results

Fig.1 shows a 2D blood velocity field measured by PC-MRA and a reconstructed velocity field with EDG method. Virtual probe position located on the proximity of the apex is expressed as cross (×) on the T2WI image shown in **Fig.1**(a). **Table.1** represents the error parameters during each of five phases in the same probe position in **Fig.1**. **Fig.2** shows the error parameters when the virtual probe positions were changed during the phases of E, ERF, and AC. The results showed that *E*tot was minimized as the probe position was changed from parasternal region to apical portion.

Table.1 Error parameters during each of five phases

Phase	E	RE	ERF	LRF	AC
*E*tot[%]	18.0	27.7	28.4	24.0	30.0

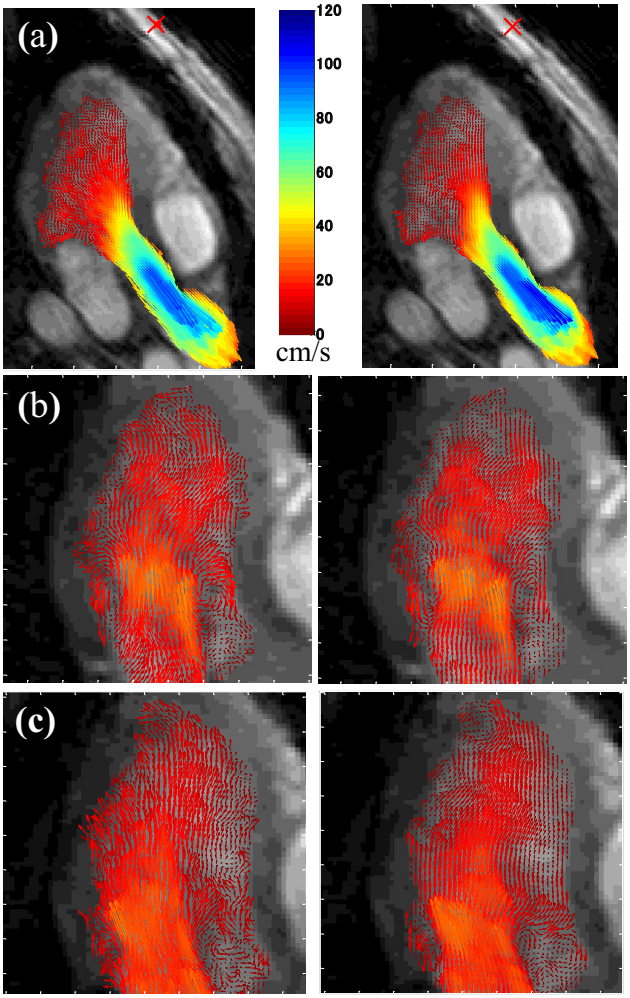
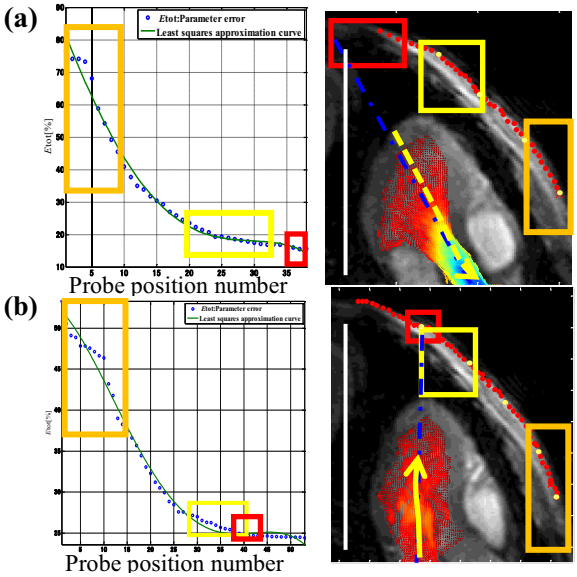


Fig.1 Blood velocity mapping in normal LV showing original PC-MRA measurements (left) and velocity field reconstructed from virtual Doppler velocity, thereby calculated by EDG (right) during (a) E, (b)ERF, (c)AC. The vectors indicate the direction and magnitude of the velocity as coded in the color bars (cm/s). Both color and arrow-length encode velocity magnitude. The cross (×) located in a proximity of apex on T2WI of (a) represents the location of virtual probe.



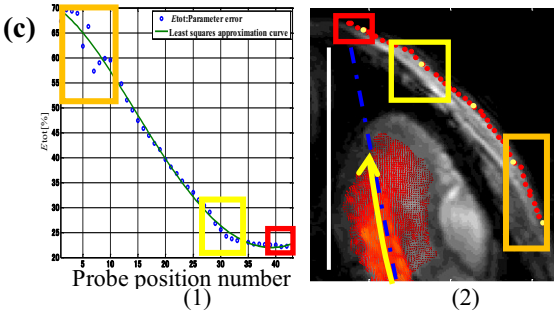


Fig.2 Error parameters depending on the location of virtual probe during (a) E, (b) ERF and (c)AC. (1)(left columns): Relative error of the total reconstructed velocity fields, with respect to the MR data as a function of the position of the ultrasound virtual probe. Blue circle shows values of ***E*tot** at each probe position. The green curves are quadratic least square fits to the data. Yellow-colored boxes indicate where ultrasound probe is located to obtain apical long axis view and orange-colored boxes indicate left parasternal long axis view. (2) (right columns) show original velocity fields measured with PC-MRA and the location of virtual probe is expressed as Red circles. Yellow circles show virtual probe position numbers 1, 10, 20, 30, and 40 following in the direction from parasternal region to apex. White lines: the scale of 14cm, yellow arrows: flow axis lines, blue dashed lines: parallel to flow axis lines, and red boxes area: where blue dashed lines are crossing.

4. Discussion

As the results of five cardiac phases when blood flow has high velocity, the difference between *in vivo* velocity field measured by PC-MRA and the field reconstructed using EDG algorithm did not show large contradictions. The results also indicate that apical long axis views have small error relative to other views. In EDG algorithm, the flow is separated into vortex flow and basic flow. It is assumed that small errors result from when a visible vortex and a main flow have no contradiction in flow fields observed from apex. On the other hand, some errors were caused from underestimating the magnitude of vortex flow component parallel to the heart wall in the flow field near the LV boundary. In conclusion, this study clearly shows that EDG for echocardiography provides important information on blood flow dynamics in clinical settings.

References

1. S. Ohtsuki and M. Tanaka: J. Vis. **9** (2006) 69
2. T. Uejima, A. Koike, H Sawada, T. Aizawa, S. Ohtsuki, M. Tanaka, T. Furukawa, and G. A. Fraser: Ultrasound in Med. & Biol. **36** (2010) 772
3. Garcia D, del Almano J.C, Tanne D, et al: IEEE Trans. Med. Imaging. **29** (2010) 1701