3P5-15

Analysis Left Ventricle Blood Flow patterns in Normal Subject by Echodynamography

Sri Oktamuliani[1†], Kaoru Hasegawa[2], and Yoshifumi Saijo[1]
([1]Graduate School of Biomedical Engineering, Tohoku University; [2]Cardiovascular, Tohoku Pharmaceutical University Hospital)

1. Introduction

Medical image processing is a dynamic field in research that has the computational load of an algorithm and many applications become part of clinical practice [1]. Medical image computing one of them is Echodynamography (EDG). The basic concept of the EDG is non-turbulent blood flows in the left ventricle (LV) that can be described as a combination of a single non-vortical laminar flow (base flow) and several vortices laminar flows (vortex flow). EDG is a revolutionary technology for making flow vector fields obtained during routine echocardiography by B-mode colour Doppler velocity data on the image **Fig. 1**.

Fig. 1 Color Doppler image of blood flow in the left ventricle by sector scan.

Precise measurement of blood flow is important for understanding local flow dynamics. Theory of fluid dynamics has been applied in EDG to estimate and display the flow distribution for investigation blood flow structure in LV both in healthy and disease case volunteer.

In the present study, the measure and analysis different parameters from blood flow distribution such as velocity, flow rate and vorticity was investigated by EDG of LV in the healthy subject.

2. Methods

The color Doppler image is an apical three-chamber view which is the left ventricle long axis image was recorded in Pro sound SSD-6500SV manufactured by Aloka Co. Ltd. The ultrasound frequency was 5 MHz and the frame rate is 30 Hz or 15 fps. The time phase is representative atrial contraction, isovolumetric contraction, ventricular ejection, and ventricular in the healthy subject.

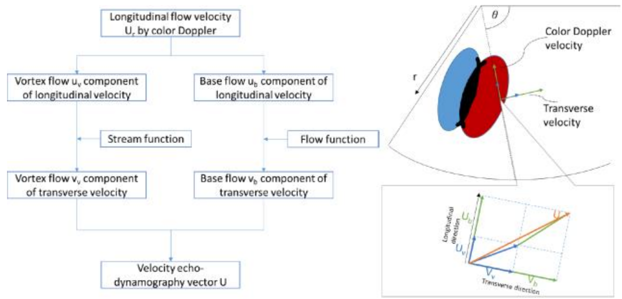

Fig. 2 Schematic diagram of Echodynamography.

In the **Fig. 2**, the base flow component of longitudinal velocity u_b and transverse velocity v_b form the flow vector of the base flow component are denoted by the green arrow. likewise, the vortex flow component of longitudinal velocity u_v and transverse velocity v_v form the flow vector of the vortex flow component are denoted by the blue arrow. The equation is:

$$\begin{aligned} u(x,y) &= u_v(x, y + u_b(x,y), \\ v(x,y) &= u_v(x,y) + v_b(x,y), \end{aligned} \quad (1)$$

In polar coordinate, Flow velocity $U(r,\theta)$ can be found by calculating:

$$U(r,\theta) = \begin{Bmatrix} \left(u_b(r,\theta) + u_v(r,\theta)\right) i(r,\theta) + \\ \left(v_b(r,\theta) + v_v(r,\theta)\right) j(r,\theta) \end{Bmatrix} \quad (2)$$

Flows which are described by a stream function undoubtedly fill the continuity equation since

$$\begin{aligned} &\frac{\delta u}{\delta x} + \frac{\delta v}{\delta y} = \frac{\delta}{\delta x}\left(\frac{\delta \Psi}{\delta y}\right) + \frac{\delta}{\delta y}\left(-\frac{\delta \Psi}{\delta x}\right) = 0, \\ &\frac{\delta^2 \Psi}{\delta x \delta y} - \frac{\delta^2 \Psi}{\delta y \delta x} = 0 \end{aligned} \quad (3)$$

Flow function (ϕ) that are perpendicular to the streamlines is used to describe inviscid and irrotational flow. ϕ and ψ are related mathematically through the velocity components:

$$u = \frac{\delta \phi}{\delta r} = \frac{1}{r}\frac{\delta \Psi}{\delta \theta}; v = \frac{1}{r}\frac{\delta \phi}{\delta \theta} = -\frac{\delta \Psi}{\delta r} \quad (4)$$

When the velocity component u in the beam direction on the scanning plane is integrated with the beam perpendicular, as the stream function in two-dimensional flow, flux is calculated. This is called the flow function *F(r,θ)* as

$$F(r,\theta) = \int_{o}^{\theta} u_b(r,\theta)\, r\, d\theta, \qquad (5)$$

where velocity data are integrated along every arc to calculate 2-D flow rate of the base flow component.

In this case, k represents the ratio of the positive flux of the vortex to the positive portion of the total flux passing through the integration boundary. Then, the ratio k is defined as

$$k = \frac{\Psi_+}{F_{c+}} \begin{cases} \text{only vortex flow } (k = 1) \\ \text{vortex flow + base flow } (0 < k < 1) \\ \text{only base flow } (k = 0) \end{cases} \qquad (6)$$

Vorticity is an important concept in fluid dynamics. The vorticity acts as a measure of the local rotation of fluid elements. Vorticity is a vector quantity and it tells us the tendency of a fluid particle to rotate or circulate at a particular point.

$$\omega(r,\theta) = \nabla \times \overline{U} = \frac{\delta r v(r,\theta)}{r \delta r} - \frac{\delta u(r,\theta)}{r \delta \theta} \qquad (7)$$

3. Results and Discussion

Echodynamography is explained as a combination of base flow and vortex flow. **Fig. 3** shown that separation coefficient of vortex flow and base flow with calculating the coefficient *k* in the cardiac cycle.

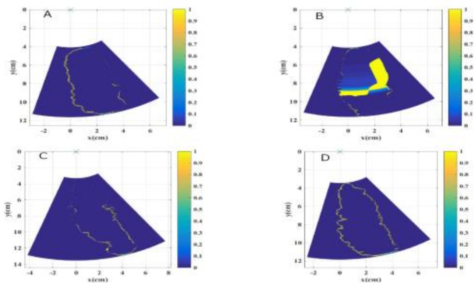

Fig. 3 Separation coefficient of base flow and vortex flow of LV in the healthy subject. (a) Atrial contraction; (b) isovolumetric contraction; (c) ventricular ejection; (d) ventricular filling.

The flow velocity is found by analyzing the spatial distribution of the 2-D flow rates within scan plane. **Fig. 4** shows velocity patterns of echodynamography in LV are about *39 cm/s* inflow and about *96 cm/s* outflow velocity.

Fig. 5 displays a comparative of vorticity of the left ventricle at each phase in the healthy subject. The maximum vorticity at atrial contraction was *-30.25/s*, the isovolumetric contraction was *-82.80/s*, ventricular ejection was *+145.88/s*, and ventricular filling was *-30/s*. Positive vorticity means the blood flows counter-clockwise while negative vorticity means the blood flows clockwise.

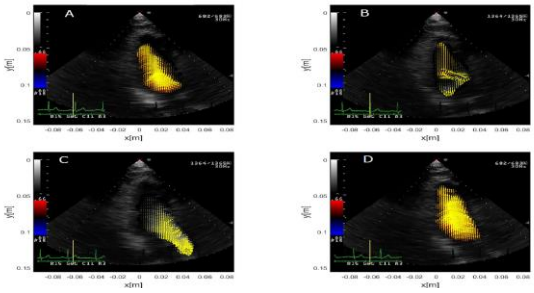

Fig. 4 Velocity vector echodynamography in the healthy subject. (a) Atrial contraction; (b) isovolumetric contraction; (c) ventricular ejection; (d) ventricular filling.

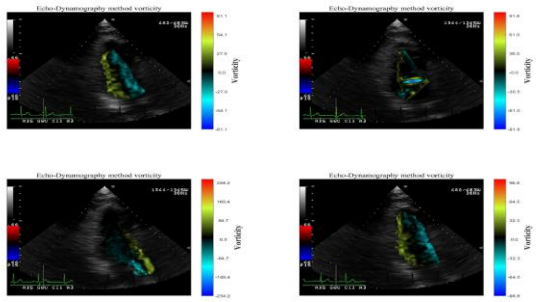

Fig. 5 Vorticity of left ventricle in the healthy subject. (a) Atrial contraction; (b) isovolumetric contraction; (c) ventricular ejection; (d) ventricular filling

4. Conclusion

The conclusion of this paper is when there is a vortex, it has some vorticity. But the reverse is not necessarily true. A base flow, which is not a vortex, has vorticity too.

Acknowledgment

I should like to acknowledge DIKTI and LPDP who have provided financial support through BUDI scholarship so I can do research and Study in Graduate School of Biomedical Engineering, Tohoku University.

References

1. H. Handels, S. Mersmann, C. Palm, T. Tolxdor, G. Wagenknecht, T. Wittenberg, et al., Viewpoints on medical image processing: from science to application, Current medical imaging reviews 9 (2) (2013) 79-88.
2. T. Kojima, A. Omori, H. Nakajima, T. Kurokawa, T. Kameyama, Y. Saijo, Validation of echo-dynamography by virtual color doppler echocardiography generated from phase contrast magnetic resonance angiography datasets, in: Engineering in Medicine and Biology Society (EMBC), 2013. 35th Annual International Conference of the IEEE, IEEE, 2013, pp. 105-108.