2P5-7

Proceedings of Symposium on Ultrasonic Electronics, Vol. 37 (2016)
16-18 November, 2016

Relative Pressure Imaging of the Left Ventricle by Ultrasonic Vector Flow Mapping
超音波 Vector Flow Mapping を用いた左室内圧分布イメージング

Tomohiko Tanaka[1†], Takashi Okada[2], Tomohide Nishiyama[2], and Yoshinori Seki[2]
([1]Research & Development Group, Hitachi Ltd., [2]Healthcare Business Unit, Hitachi Ltd.)
田中 智彦 [1†], 岡田孝 [2], 西山知秀 [2], 関佳徳 [2], ([1]株式会社日立製作所　研究開発グループ, [2]株式会社日立製作所　ヘルスケアビジネスユニット)

1. Introduction

Intracardiac pressure distribution sensitively reflects cardiac performance through the cardiac cycle. Intraventricular pressure differences (IVPDs) are closely related to left ventricular (LV) elastic recoil and early ventricular suction [1], namely, lower pressure at the apex than that at the base of LV. Deriving regional pressure differences in the LV appears to be a powerful approach for not only pathophysiological investigation of the cardiac function but also clinical assessment of ventricular systolic and diastolic functions [2].

Recently, to demonstrate the physiological relation between flows and relative pressures several approaches to visualize relative pressure in the LV, using pcMRI [3-6] and ultrasound vector flow mapping (VFM) [7], have been studied, and relative pressure imaging (RPI) is expected to open up new prospects for diagnosis of cardiac functions. Of these methods, ultrasound-based RPI can easily visualize pressure distribution; however, ultrasonic RPI has not been validated. The objective of the present study is thus to experimentally validate RPI based on VFM.

2. Materials and Methods

2.1 Relative pressure imaging

RPIs are calculated on the basis of 2D VFM velocity fields by applying the momentum conservation law, where the VFM fields were calculated by following Itatani's approach [8]. The velocity field is calculated by color flow mapping, and LV-wall velocities were calculated by tissue tracking. The VFM derivation is described in detail in their article.

In the present study, the momentum conservation law, namely, the Navier-Stokes equation, for incompressible fluids was used for calculating RPI.

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = -\frac{1}{\rho}\frac{\partial p}{\partial x_i} + \nu\left(\frac{\partial^2 u_i}{\partial x_j \partial x_j}\right) \qquad (1)$$

Variables u, x, p, ρ, and ν, represent velocity, position, pressure, density, and kinematic viscosity of the fluid, respectively. Subscripts 1, 2, and 3 denote directions in the Cartesian coordinate system. The first and second terms on the left-hand side are the inertial and convective terms, respectively. Also, the first and second terms on the right-hand side are pressure and viscous terms.

2.2 Experimental validations

The LV phantom used for experimentally validating RPI based on VFM was the same as that used for our previous VFM-velocity validation studies [9]. The LV phantom was made of urethane resin on the basis of 3D LV data, as shown in **Fig. 1**. The phantom was passively pulsated by changing the chamber pressure, which was controlled by a pressure piston (F14-10, Yamaha Motor Co., Ltd.). The chamber had an acoustic window on the lower side, and an ultrasound probe was attached to the window.

An ultrasound scanner (ProSound 10, Hitachi Ltd.) with a sector probe (UST-52105, Hitachi Ltd.) with a center frequency of 2.5 MHz acquired color Doppler and B-mode images of about 30 heart beats in each experiment.

Two-point intraventricular pressure difference (IVPD) was measured by a pressure catheter with two pressure sensors, (Mikro-Tip Pressure Catheter,

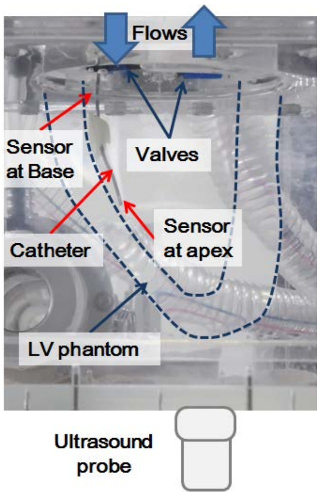

Fig. 1. Schematics of LV phantom.

SPR-956S, Millar Instruments Inc.) at a sampling rate of 2.5 kHz, installed in the LV phantom (Fig. 1). One sensor was located right below the mitral valve, and the other was located 50 mm from the first one. Intraventricular pressure difference (IVPD) between the two sensors was compared with that given by RPI.

IVPD based on color M-mode [10] was also calculated for comparison. The IVPD was calculated by integrating the 1D Euler equation from a position closest to the mitral valve and a position 50 mm apart along the M-mode beam. In the present study, 30-beat M-mode velocity data were averaged before applying the 1D Euler equation.

3. Results and discussions

RPI results obtained in the early diastole at a frame rate of 35 Hz are shown in Figure 2. The upper and bottom parts denote the apex and base positions, respectively. In the early diastole, a remarkable suction, namely, lower pressure at the apex than that at the base, is observed.

The calculation of relative pressure consists of inertial, convective, and viscous effects. As shown in Figs. 2(b) to (d), each term was considered separately. The figures show that the inertial term mainly contributes to suction, while the convective term is smaller, and the viscous term is negligible.

The calculated and measured pressure differences in the diastolic phase, namely, RPI-based IVPD, catheter-measured IVPD, and color-M-mode-based IVPD, are plotted in Figure 3. The error bar denotes the 95% confidence interval. In the period from t = 0.4 s to 0.42 s, the color-M-mode data are degraded by a strong ultrasound reflection by the mechanical valve opening, so they were omitted. Comparing the three pressure-difference lines shows they are in good agreement. However, the peak value calculated by RPI was underestimated by 37% (due to relatively lower frame rate) compared with that calculated by color M-mode (with higher time resolution). It is expected that imaging methods with better resolution (such as ultrafast imaging) will resolve this underestimation. (Further analysis will be shown in the presentation.)

4. Conclusions

RPI based on VFM was quantitatively validated by a phantom experiment. This experimental verification suggests the RPI would be a reliable tool for possible future diagnosis of heart diseases.

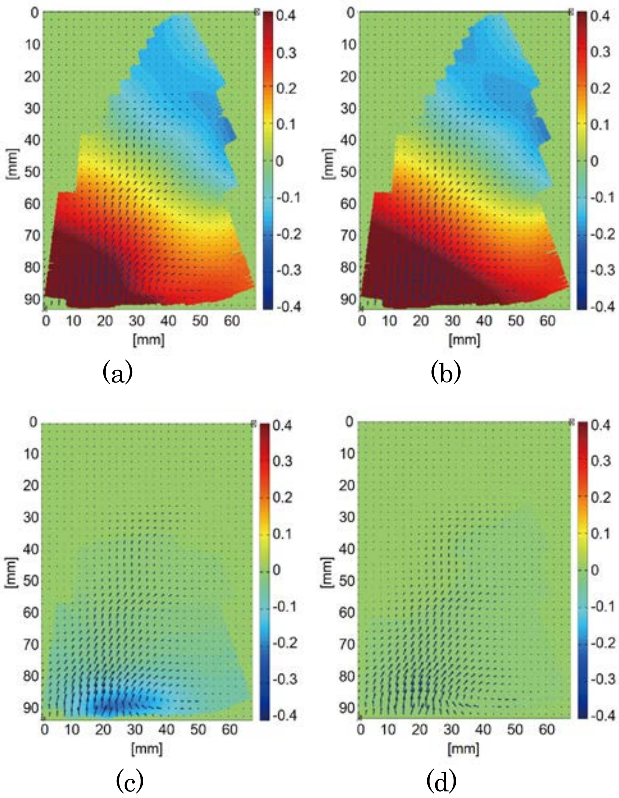

Fig. 2. RPI results calculated on the basis of (a) all terms, (b) inertial term, (c) convective term, and (d) viscous term.

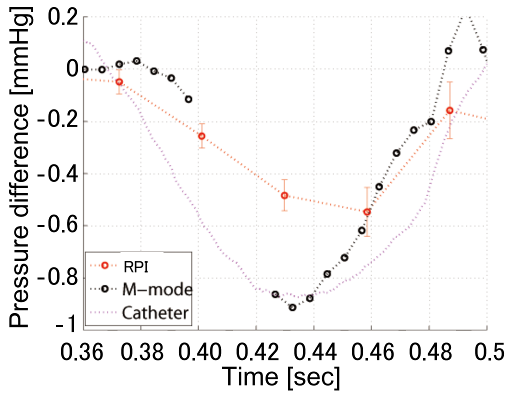

Fig. 3. Comparisons of pressure difference in diastolic phase determined by RPI-based IVPD, catheter measurement, and color-M-mode-based IVPD.

References

1. M. Courtois et al.: Circulation **81** (1990) 1688.
2. J.D. Thomas and Z.B. Popovic: Circulation **112** (2005) 1684.
3. G.Z. Yang et al.: Magn Reson Med **36** (1996): 520.
4. J.M. Tyszka et al.: J Magn Reson Imaging **12** (2000) 321.
5. F. Buyens et al.: Magn Reson Med **53** (2005) 877.
6. H. Wen et al.: Magn Reson Med **54** (2005) 538.
7. G. Pedrizzetti et al.: Nature Reviews Cardiology **11** (2014) 545.
8. K. Itatani et al.: Japanese Journal of Applied Physics **52** (2013) 07HF16-1-13.
9. T. Tanaka et al.: IEEE IUS (2012）.
10. N.L. Greenberg et al.: Am J Physiol **271** (1996) H1267

mailto:tomohiko.tanaka.nx@hitachi.com