High frame rate echoPIV reveals the transient flow patterns in heart failure patients

Jason Voorneveld1, Lana B.H. Keijzer2, Mihai Strachinaru1,2, Dan J. Bowen2, Jeffrey S.L. Goei2, Antonius F.W. van der Steen1, Folkert Ten Cate2, N. de Jong1, Hendrik J. Vos1, Annemien E. van den Bosch2, Johan G. Bosch1

1Department of Biomedical Engineering, Thorax Center, Erasmus MC, Rotterdam, Netherlands
2Department of Cardiology, Thorax Center, Erasmus MC, Rotterdam, Netherlands
Corresponding author: j.voorneveld.at.erasmusmc.nl

Introduction

Study of left ventricular (LV) flow patterns may reveal early stage biomarkers of cardiac dysfunction[1]. However, standard clinically available techniques for flow estimation, such as color and pulsed-wave (PW) Doppler, are limited to measuring only the axial velocity component s. Echo-particle image velocimetry (echoPIV) is an image processing technique that tracks the displacement of ultrasound contrast agent (UCA) microbubbles to estimate flow patterns in 2D. However, echoPIV using standard line-scanning echocardiography (~50 fps) is known to severely underestimate the high velocity flows associated with diastolic filling [2]. High frame rate (HFR) echocardiography, using diverging wave transmission sequences, can be benifical with frame rates 100x that of standard line-scanning echocardiography. We have shown previously, in an in vitro LV model, that HFR echoPIV can accurately estimate the high velocity flows associated with diastolic filling [3]. In this study we assess whether the use of HFR echoPIV can also estimate the transient and high velocity diastolic flow patterns in patients with heart failure.

Methods

Preliminary data from a single patient (out of a 20 patient group) with heart failure was scanned using both a clinical scanner (Phillips EPIQ 7, Phillips) and an open research scanner (Verasonics Vantage 256, Verasonics). The clinical scanner was used to obtain PW Doppler estimates at the mitral valve and aortic outflow tract, as well as to verify that the desired UCA concentration was obtained in the LV. Continuous infusion of UCA (SonoVue®, Bracco) was administered at 0.6 ml/min using an infusion pump (VueJect BR-INF 100, Bracco). For the HFR acquisitions, a P4-1 probe (center frequency = 1.5 MHz, ATL) was used to transmit two-angled (-7°, 7°) diverging-waves in a pulse-inversion sequence at a PRF of 4900 Hz, resulting in an imaging frame rate of 1225 Hz. For echoPIV analysis a custom PIV implementation was used that calculated correlation for each angle separately [3]. Subsequently, correlation compounding was performed on 5 frames of each angle to further improve SNR (10 frames total correlation compounding), resulting in a vector-frame rate of 244 Hz. Normalized cross-correlation was performed in the polar domain with an iterative, window refinement and deformation scheme [4]. Kernel size was 10° by 10mm for 3 iterations, followed by 5° by 5mm for 2 iterations, with an overlap of 75%, resulting in a final grid resolution of 1.25° by 1.25 mm. Post-processing included a 3-element temporal moving average and 3x3 gaussian spatial smoothing filter.

Results

HFR echoPIV vector sequences were obtained at 244 Hz, allowing for detailed flow structures to be followed as they develop and traverse the scan-plane (Figure 1. Right). The diastolic jet velocities corresponded well with the PW Doppler spectrum obtained in the same location (Figure 1. Top-left). Systolic correspondence was also good but the systolic HFR echoPIV data had more variance than in the diastolic position (Figure 1. Bottom-left).
Conclusions

High frame rate echoPIV could measure the high velocity diastolic and systolic jets of the left ventricular in 2D, with good correspondence to PW Doppler. Additionally, the high temporal resolution of the calculated vectors may reveal transient flow structures that would otherwise go unnoticed when using low frame rate imaging sequences.

References


