Volumetric, 3D velocity Encoded Valve Imaging with Radial Undersampling

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INTRODUCTION

Phase contrast (PC) MR velocimetry can be utilized to provide velocity measurements which can be processed to yield hemodynamic parameters such as flow, wall shear stress, and relative pressure. However, the application of PC to cardiac valve imaging offers unique challenges. As the valve location changes as much as 30mm within the cardiac cycle, current methods rely on high contrast cine SSFP localizers to estimate the valve locations at the different cardiac cycles. This allows a series of 2D single directional PC exams to be acquired at the different cardiac phases at the approximate valve locations. This is a time consuming process and requires multiple patient breatholds. An attractive alternative is 3D PC covering a modest slab, with three directional velocity encoding [1], so that the valve plane can be tracked retrospectively throughout the cardiac cycle and images reformatted to match the appropriate orientation. Additionally, the ability to reformat allows us to simultaneously image either the mitral (MV) and triscuspid (TV) valves or the aortic(AV) and pulmonary(PV) valves. However, due to the need for respiratory motion compensation, cardiac gating, and both high temporal and spatial resolution clinically feasible scan times are not easily achieved. While 3D PC can be accelerated by sacrificing spatial resolution through a combination of limited phase encoding and no respiratory gating/navigation and an unbalanced velocity encoding with a EPI readout; the resolution loss and flow sensitivity introduced will substantially limit the clinical utility. In this work, we investigate the combination of rapid radial trajectories and respiratory motion compensation as an alternative.

METHODS

A 3D hybrid radial PC sequence, phase encoded in the slab direction with radial readout in-plane, with three directions flow encoding was implemented with cardiac and respiratory gating [2]. Respiratory gating is achieved utilizing a diminishing variance algorithm, which repeats data point at the end of the scan that are considered motion corrupted as determined by a respiratory bellows. All experiments were performed on a clinical 3T scanner with 20 elements of a 32-channel torso coil (MR 750, GE Healthcare, Waukesha, WI). Scans were prescribed obliquely, to image either the mitral (MV) and triscuspid (TV) valves or the aortic(AV) and pulmonary(PV) valves. In either case, one valve would be in plane (for example, the MV), while the other (the TV) was at a slight angle. However, the high spatial resolution and three directional velocity encoding combined with sufficient slab thickness allows cardiac gated flow measurements to be performed on the reformatted images with minimal loss of information. An 11 minute 32 second exam consisting of 34 heart beats per slice encode was acquired using the Golden Angle sampling scheme[3]. This data set allowed us to retrospectively sample the acquired data to study the effects of various degrees of undersampling on image quality and quantitative flow imaging. Furthermore, it allows for reconstructions around any of the 25 cardiac phases with approximately uniform projection spacing. The data was decimated to simulate scantimes of 5:46 ,4:04 and 3:03 and compared to the full dataset and a reference 2D Cartesian acquisition. Additional parameters include: FOV = 320 x 320 x 48 mm, spatial resolution 1.25 x 1.25 x 4.0 mm, temporal resolution 83ms. Other parameters include venc = 150cm/s, ±62.5 kHz readout bandwidth, TR =6.9ms, TE=3.3ms, α=10°. An additional 20s gradient calibration scan was acquired immediately following acquisition to correct for errors from eddy currents and gradient timing errors [4]. Angiographic images were analyzed for vessel conspicuity, artifact prevalence and flow was calculated from the velocity images.

RESULTS

To demonstrate the ability to perform flow measurements through the valves not originally in plane, the images were reformatted with the tricuspid and aortic vales now in plane. Magnitude and complex difference images provide the anatomical map, while the velocity images are used in flow measurements. Another important parameter, maximum velocity, was measured to be 122.5 cm/s in the 2D image, and ranged from 114.8 cm/s (the set using 9 beats/slice encode) to 125.9 cm/s in the dataset using 17 beats/slice encode.

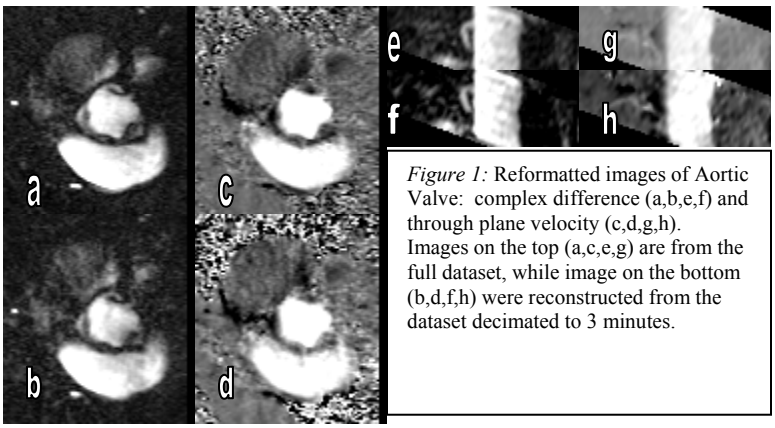

Figure 1: Reformatted images of Aortic Valve: complex difference (a,b,e,f) and through plane velocity (c,d,g,h). Images on the top (a,c,e,g) are from the full dataset, while image on the bottom (b,d,f,h) were reconstructed from the dataset decimated to 3 minutes.

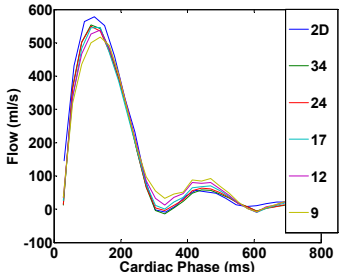

*Figure 2:*Flow through the aortic valve measured using the decimated data sets. The legend indicates the number of hearts beats per slice encode used for each dataset. 2D corresponds to the clinical 2D Cartesian acquisition.

DISCUSSION

In this study, we demonstrated the potential for time resolved, 3D PC imaging of the cardiac valves in a reasonable scan time with both high spatial and temporal resolution using SOS sampling. Even though the valves move considerably throughout the cardiac cycle and are not necessarily in plane, the high spatial resolution and three directional velocity encoding allow for multiple reformations to be performed in any desired imaging plane for flow quantification. Note that even after several reformats, the spatial resolution and three directional encoding show depiction of the right coronary artery (e-f). In addition, the 3D acquisition allows for segmentation of the valve to track the valve plane throughout the cardiac cycle. Without the need to accurately estimate the valve locations and orientations before the PC exam, the time required for scan prescription is reduced, thereby minimizing patient discomfort associated with breatholds during this process.

REFERENCES

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