Motion-tracked imaging of the aortic valve with super-resolution enhancement

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Introduction

Visualisation of the morphological structure and dynamics of the valve leaflets could assist computational fluid dynamic studies of blood flow (1) and lead to a greater understanding of the pathogenesis and development of valvular heart disease. Magnetic resonance imaging of the aortic valve is usually performed in a plane perpendicular to the root of the aorta and is complicated by the rapid opening and closing of the valve leaflets and by the through-plane motion of the valve plane as the heart contracts and relaxes. This through-plane motion was recognised by Kozerke et al. who developed a phase velocity mapping sequence which tracked the through-plane motion of the valve plane (2) in order to obtain a more accurate determination of regurgitant flow. The aim of this work is to extend the motion-tracking approach so that the plane of interest is tracked in two orthogonal long axis planes and to use it for imaging valve morphology. The motion tracking is used in conjunction with the super-resolution technique (3) to build up a high SNR motion-tracked volume from multiple over-lapping 2D images which depict the valve morphology as a function of time.

Methods

A cine gre-epi sequence with a labelling pre-pulse (selective and non-selective 90^0 pulse pair) was implemented on a Siemens Avanto 1.5Tesla scanner. Interleaved cine acquisitions showing the aortic outflow tract in two perpendicular long axis planes were acquired during a single breath-hold, with the labelling being performed perpendicular to both planes and approximately 15mm below the level of the aortic valve. The resulting images show the motion of the labelled slice through the cardiac cycle in both planes. The labelled slice was tracked automatically by multi-resolution image registration (4) and the end points cubic spline interpolated between time points so that the normal vectors and position offsets of the tracked plane could be derived at any required time-point in the cardiac cycle. A segmented FLASH sequence was modified to read a text file containing the tracked image plane parameters and to adjust the image plane orientation and slice offset for each RF pulse in the cardiac cycle accordingly. Multiple overlapping through-plane tracked 2D breath-hold images of the valve plane were acquired with a pixel size of 1.2mm x 2.4mm x 8mm. Each acquisition was shifted by 2mm in the slice-select direction with full coverage of the valve plane being achieved in 16 – 20 breath-holds, each taking 16 cardiac cycles to acquire. Acquisitions were performed both with and without motion-tracking.

Results

Figure 1 shows end diastolic and end systolic images of two long axis planes showing the aortic outflow tract, with the position of the labelled plane being indicated on each. The maximum excursion of the tracked plane in this example was 16mm. Figure 2(a) shows five frames from a standard segmented FLASH acquisition showing the opening and closing of the aortic valve with through-plane motion of the valve plane resulting in its poor visualisation. Figure 2(b) shows the same acquisition with motion-tracking, the image plane orientations and offsets through the cardiac cycle being determined from the tagged images shown in Figure 1. In contrast to Figure 2(a), the valve leaflets remain within the image plane throughout the cardiac cycle resulting in their clear depiction. Acquiring an overlapping stack of such images enables super-resolution to be implemented using projection onto convex sets to increase the resolution and/or SNR in the slice-select direction. This is demonstrated in Figure 2(c) where the SNR is increased and partial-volume effects reduced, resulting in a clearer depiction of the leaflets. A volume rendering of the super-resolved datasets showing the valve in late systole is shown in Figure 3.

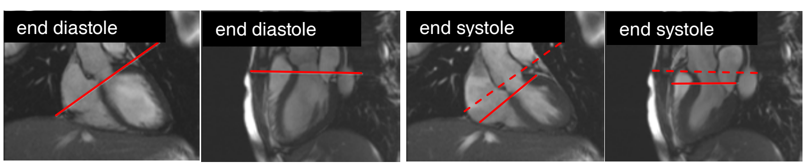

Figure 1: Diastolic and systolic images showing the aortic outflow tract. The labelling prepulse is positioned on the diastolic images approximately 15mm from the valve plane (solid red line). The position of the labelled plane in systole is noted on the systolic images (solid red line). For comparison, the systolic images also show the position of the labelled plane in diastole (dotted red line).

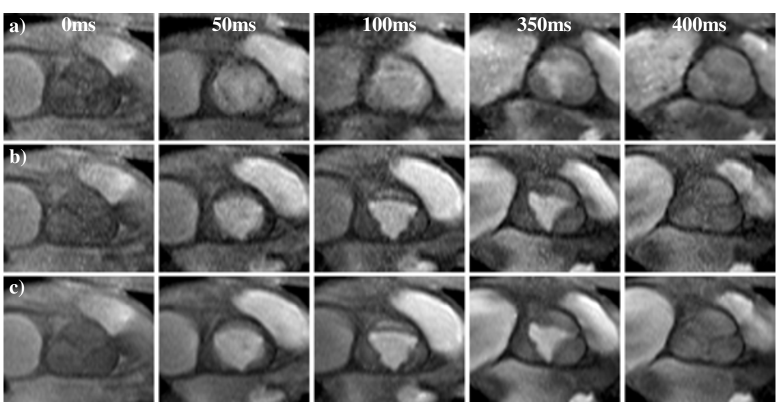

Figure 2: Five frames from untracked (a), motion-tracked (b) and super-resolved motion-tracked (c) data acquisitions of the valve plane.

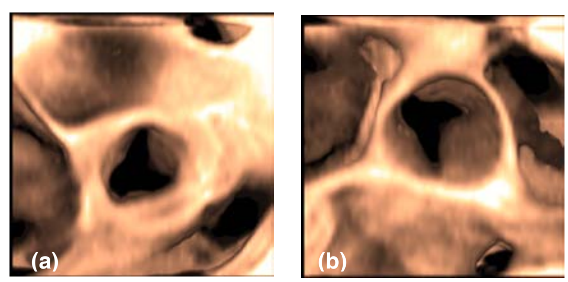

Figure 3: 3D reconstructions of the aortic valve in late systole (350ms) viewed from the left ventricle (a) and from the aorta (b).

Conclusion

Implementing through-plane motion-tracking improves the visualisation of the aortic valve throughout the cardiac cycle. The use of super-resolution in the slice-select direction has enhanced the image quality by reducing partial volume effects and has allowed the reconstruction of a motion-tracked volume which shows the dynamic structure of the valve leaflets and which is suitable for input to computational fluid dynamic simulations of blood flow. This approach would also be expected to increase the accuracy of planimetric assessment of aortic valve disease.

References

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