Cardiac-respiratory self-gated cine UTE for visualization of the cardiac valves

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Target audience: Physicists who are interested in cardiovascular MRI and method and processing development.

Purpose: Cardiovascular magnetic resonance imaging (CMR) often suffers from electrocardiogram (ECG)-trigger, flow and susceptibility artifacts, which all may hamper either quantitative functional analysis, characterization of cardiac valve dysfunctions, or observation of responses to therapeutic interventions [1]. While several concepts to replace ECG gating have been proposed, including acoustic gating [2] or retrospective strategies [3,4] no convincing solutions are established so far to minimize flow and susceptibility artifacts. Here, we have implemented a cardiac and respiratory self-gated ultra-short echo time (UTE) sequence to remedy these problems (Fig.1). We compared the self-gated UTE sequence with a self-gated fast low angle shot (FLASH) sequence in terms of image quality, functional cardiac characterization and observation of the cardiac valves. To further improve the observation of the cardiac valves a novel visualization technique termed Reflection Point visualization was established.

Methods: MRI measurements were performed on six 12-weeks old healthy female C57BL/6 wild-type mice. *MRI protocols*: 2D self-gated cine UTE (slice thickness: 1mm, TE/TR=399 µs/6.2 ms, flip angle: 15°, field of view: 20x20 mm^2, resolution: 129x129 µm^2, number of projection: 246, polar undersampling: 2) and self-gated (IntraGate, Bruker, Biospin MRI, Ettlingen, Germany) cine FLASH (slice thickness: 1mm, TE/TR=3 ms/6.2 ms, flip angle: 15°, field of view: 30x30 mm^2, resolution: 129x129 µm^2) sequences were acquired at 9.4 T on a Bruker BioSpec94/20. For the visualization of the four different cardiac valves multi-slice images were acquired by self-gated cine UTE using the IntraAngio tool (Bruker, BioSpin, MRI; slices: 7, slice thickness: 0.8 mm, interslice distance 0.4 mm, TE/TR=338 µs/5.5 ms, flip angle: 15°, field of view: 30x30 mm^2, resolution: 129x129, number of projections: 728). *Refection Point visualization technique*: The technique was implemented within the IntraGate tool. In the image domain data a Reflection Point is defined by the signal intensity of the tissue of interest and mirrors all signal intensities in a way that pixel intensities of images are displayed according to their distance to the Reflection Point. The smaller the distance to the Reflection Point, the brighter the pixels are pictured. Thus tissue interfaces can be enhanced. *Analysis of cardiac parameters:* Volume of the left and right ventricular myocardium (LVM, RVM) as well as the end-diastolic and systolic volume (EDV, ESV) was segmented manually in MR images using Amira software (Version 5.4.0, Visage Imaging GmbH, Berlin).

Results and Discussion: Self-gated cine UTE provided high quality images with high contrast to noise ratio (CNR) between blood and myocardium (CNR: 22.68±5.28). Excellent contrast was also observed between the right myocardium and the surrounding tissue ($CNR_{myocardium\_liver}$: 6.98±2.21). Functional parameters such as LV and RV myocardial mass (LVM: 84±3 mg, RVM: 19±4 mg), stroke volume (LVSV: 32.3±6.5 µl, RVSV: 22.6±3.9 µl), ejection fraction (LVEF: 71.8±2.2%, RVEF: 69.6±3.2%) and cardiac output (LVCO: 15.6±3.8 [ml/min], RVCO: 10.9±2.1 [ml/min]) were identical to the values measured with self-gated cine FLASH (LVM: 84±6 mg, RVM: 15±4 mg, LVSV: 32.3±6.9 µl, RVSV: 22.9±3.5 µl, LVEF: 72.2±3.2 %, RVEF: 72.4±6.1 %, LVCO: 15.6±3.8 [ml/min], RVCO: 11.0±2.2 [ml/min]). Compared to cine FLASH images, susceptibility, motion, and flow artifacts were substantially decreased due to the short TE of 399 µs. The aortic valve was clearly discernible over the entire cardiac cycle (Fig.2). To further improve the observation of the moving valves, Reflection Point visualization was used highlighting valvular tissue in particular and tissue interfaces in general (Fig.3). By setting the Reflection Point to the signal intensity of the cardiac valves, the valves became brightest. Compared to common windowing techniques the Reflection Point approach did not only highlight the tissue of interest, but also preserved partial volume effects. This novel visualization technique allowed for a clear observation of the movement of the four cardiac valves: aortic, mitral, pulmonary and tricuspidal valve, during the full cardiac cycle.

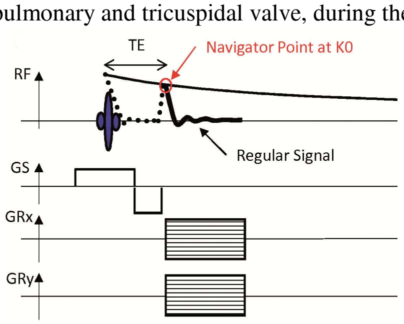

Fig.1: Pulse sequence for self-gated cine UTE: the first data point contains all required motion information and is used as navigator point without requiring additional experimental time or prolonging TE.

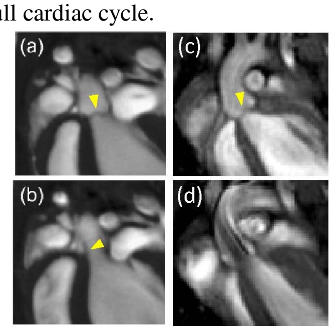

Fig.2: Self-gated cine UTE (a+b) and FLASH (c+d) images of the aortic valve in (a+c) closed and (b+d) open position (yellow arrow-head).

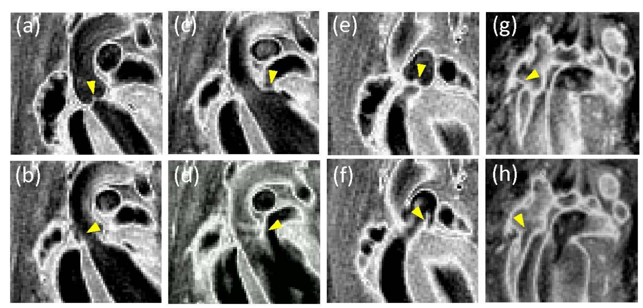

Fig.3: Self-gated cine UTE images of the cardiac valves in close (a,c,e,f) and open (b,d,f,h) position. (a+b) aortic valve, (c+d) mitral valve, (e+f) pulmonary valve and (g+h) tricuspidal valve (yellow arrowhead). Images were visualized by Reflection Point technique.

Conclusion: Self-gated cine UTE allows for robust measurement of cardiac parameters of diagnostic interest. Image quality is superior to self-gated cine FLASH. By using the Reflection Point technique a clear visualization of the moving cardiac valves was achieved. The detailed morphological valvular visualization together with the accurate functional cardiac analysis makes self-gated cine UTE a powerful tool for the assessment of cardiac valve dysfunctions.

References: [1] J.D. Miller et al., Circ Res. 2011, 108:1392-412. [2] A.C.Brau et al., Magn Reson Med. 2002, 47:314-321. [3] S.M.Bovens et al., NMR Biomed. 2011, 24:307-315. [4] E.Heijman et al., NMR Biomed. 2007, 20:439-447.