Real-time imaging of the heart and aorta at 7.0 T using a 16 channel bow tie antenna transceiver array

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Target audience: Basic researchers and clinical scientists interested in novel MR technology applications at ultrahigh fields (UHF) including 7.0 T.

Purpose: Cardiac chamber quantification and left ventricular function (LV) assessment are of key clinical relevance to diagnose and monitor cardiac diseases – the forte of cardiac MR (CMR). Conventional CMR is not a real-time imaging modality. Breath-held 2D CINE acquisitions segmented over regular 10-16 heartbeats are the clinical standard for LV function assessment. Yet, the traditional approach is constrained by physiological (e.g. cardiac arrhythmias) constraints, which limits the diagnostic capabilities of today's CMR. Offsetting this shortcoming provides a strong driving force for explorations into real-time imaging of the heart. Realizing the spatial resolution constraints of real time imaging at lower magnetic field strengths and recognizing the sensitivity gain inherent to ultrahigh magnetic fields it is conceptually appealing to pursue real time imaging of the heart at 7.0 T. To meet this goal this work examines the applicability of free breathing real time imaging of the heart and the aorta with a frame rate of 30 frames per second facilitated by highly undersampled radial 2D FLASH imaging. For this purpose a sixteen channel bow tie dipole transceiver array tailored for cardiac MR at 7.0 T is employed. For comparison traditional 2D CINE FLASH imaging of the heart and aorta is performed.

Methods: Free breathing real time imaging of the heart and aorta were conducted using a 7.0 T whole body MR system (Magnetom, Siemens, Erlangen, Germany). To meet the needs of real time MR a 16 channel TX/RX array tailored for cardiac MR was used. The transceiver cardiac array consists of 16 independent building blocks each containing a bow tie shaped λ/2-dipole antenna immersed in deuteriumoxide (D_2O) as high dielectric medium. EMF and SAR_{10g} simulations were performed using CST Studio Suite 2011 (CST AG, Darmstadt, Germany) together with human voxel models Duke (BMI: 23.1 kg/m²) and Ella (BMI: 22 kg/m²) from the Virtual Family. For transmission field shaping a phase based shimming approach based on EMF simulations using a uniformity and efficiency governed merit function was applied [1]. The phase setting deduced from the shimming algorithm was incorporated into the splitting network hardware connected to the 16 bow tie antenna array using phase shifting coaxial cables. Real time imaging of the heart and the aorta was conducted with a highly undersampled radial 2D FLASH sequence in conjunction with a nonlinear inverse reconstruction [2-5] to achieve a frame rate of 30 frames/s. Basic imaging parameters included TR = 2.56 ms, FOV = (256 x 256) mm^2, slice thickness = 6 mm, flip angle =15°, and 13 radial spokes per frame (image acquisition time = 33.3 ms). Short axis views of the heart were acquired using a read-out of 208 points per spoke and TE = 1.59 ms. For real time imaging of the aorta was 192 read-out points per spoke were employed together with a TE of 52 ms. For comparison conventional 2D CINE images of the same slices were acquired using 2D CINE FLASH with (1.1 x 1.1) mm² in-plane resolution and 2.5 mm slice thickness. For both acquisition techniques an M-mode like image post-processing approach was applied to assess the spatio-temporal evaluation of the myocardial and blood signal intensities throughout the cardiac cycle (i) along a horizontal line through the short axis view describing the orientation of the four chamber view of the heart and (ii) along a vertical line through the aortic arch.

Results: The accelerated imaging capabilities and the anatomic coverage of the 16 channel bow tie antenna array supported free breathing real time imaging of the heart (Fig. 1) and the aorta (Fig. 2) with undersampling factors up to 25. Nonlinear inverse reconstruction supported real time imaging (i) of short (Fig. 1) of the heart with a spatial resolution of (1.2 x 1.2 x 6.0) mm^3 and (ii) of the aorta (Fig. 2) with an spatial resolution of (1.3 x 1.3 x 6.0) mm² at a rate of 30 frames per second. The real time and the 2D CINE FLASH images of the aorta demonstrated the extended anatomic coverage of the 16 channel bow tie antenna array along the head-feet direction (Fig. 2) including details of the liver and the spine without B_1^+ signal voids. Fig. 1 and Fig. 2 also include M-mode like representations for a profile across the aortic arch and short axis view of the heart derived from real time and from conventional segmented CINE acquisitions to illustrate the spatiotemporal fidelity of the signal intensity evolution for blood and myocardium throughout the cardiac cycle.

Discussion and Conclusion: Our findings demonstrate that the 16 channel bow tie antenna arrays supports an extended S-I coverage using a FOV as large as 35 cm along the head-feet direction. The spatial resolution of (1.2 x 1.2 x 6.0) mm^3 and the frame rate of 30 frames per second fully meet if not excel the requirements of standardized left ventricular structure and function assessment protocols commonly used in today's CMR practice. We anticipate an extension of our in vivo feasibility study into careful evaluation of the clinical accuracy and efficacy of free breathing real time CMR at 7.0 T before variances due to (patho)physiology are introduced.

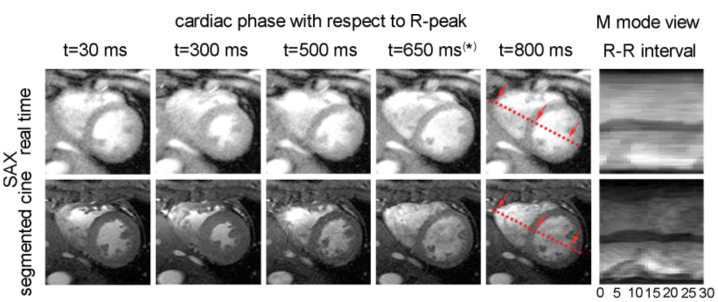

Figure 1: Results derived from free breathing real time imaging (top) and segmented 2D CINE FLASH imaging (bottom) of a mid-ventricular short axis view of the heart. Images were acquired at a rate of 30 frames per second using highly undersampled radial 2D FLASH with nonlinear inverse reconstruction at a spatial resolution of (1.2 x 1.2 x 6.0) mm^3. Right) M-mode like representations for a profile (dotted line) through short axis view of the heart derived from real time and from conventional, segmented CINE acquisitions to illustrate the spatiotemporal fidelity of the signal intensity evolution for blood and myocardium throughout the cardiac cycle.

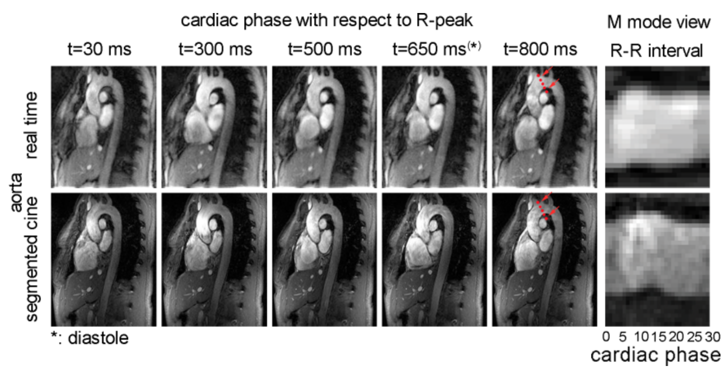

Figure 2: Results derived from free breathing real time imaging (top) and segmented 2D CINE FLASH imaging (bottom) of the aorta. Images were acquired at a rate of 30 frames per second using highly undersampled radial 2D FLASH with nonlinear inverse reconstruction at a spatial resolution of (1.3 x 1.3 x 6.0) mm^3. Right) M-mode like representations for a profile (dotted lines) through the aortic arch derived from real time and from conventional, segmented CINE acquisitions to illustrate the spatiotemporal fidelity of the signal intensity evolution for aortic blood and throughout the cardiac cycle.

References: [1] Bitz, et. Al., MRM 2010, [2] Zhang, et. Al, JMRI 2010, [3] Zhang, et. Al, JCMR 2010, [4] Uecker, et. Al, NMR Biomed. 2010, [5] Uecker, et. Al, MRM 2010