High spatial resolution functional cardiac MRI in mice using a cryogenic RF probe

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Introduction: Rapid phenotyping, assessment of gender effects and evaluation of novel therapeutics in longitudinal studies using high spatial resolution cardiac MRI (CMR) is of increasing interest for a variety of mouse models of cardiovascular diseases. Dynamic imaging of the heart allows for the assessment of cardiac morphology, function, chamber quantification and wall motion. This requires high tissue/blood contrast, full coverage of the cardiac cycle with high temporal resolution, but also high spatial resolution for a sufficient delineation of myocardial boundaries to facilitate a reliable segmentation. Challenges are physiological motion and signal-to-noise ratio (SNR) constraints. CMR may benefit from enhancements in image quality driven by improvements in the spatial resolution. SNR constraints can be offset by use of a cryogenic RF probe, which are widely used in NRM but have only recently become available for MRI systems. Yet, significant gains in SNR with a cryogenic probe have been shown for MRI of the mouse brain [1,2,3]. To this end study examines the feasibility and potential benefit of high spatial resolution functional cardiac MRI employing a cryogenic transceive RF surface coil. For comparison, a conventional mouse heart receiver array/body resonator combination is used.

Materials and Methods: All experiments were conducted on a 9.4T small animal MRI system (Biospec 94/20, Bruker Biospin, Ettlingen Germany) equipped with **(i)** a cryogenic transceive quadrature RF surface coil **(CP)** (operating at 77K and 400MHz, CryoProbe, Bruker Biospin, Ettlingen, Germany) and **(ii)** a conventional birdcage resonator in conjunction with a four channel mouse receive only cardiac coil array at room temperature **(RT)**. Functional cardiac images in C57BL6 mice were obtained with both coils using two retrospectively gated bright blood FLASH sequence [4] protocols each: **1)** a standard protocol (voxel size = 117x117x800um³, TE/TR = 2.1/8.9ms, α = 25°, BW = 75kHz, TA ≈ 2min) similar to [5] and **2)** a high spatial resolution protocol (voxel size = 55x55x800um³, TE/TR = 1.8/7.8ms, α = 20°, BW = 100kHz, TA ≈ 4min). In-slice navigation was used in a mid-ventricular short axis view with 20 reconstructed cardiac phases. SNR was estimated by dividing the mean signal intensity of the left ventricular myocardium by the noise standard deviation within a region of interest in the background.

Results: Cardiac imaging of mice using the cryogenic probe is feasible but requires the mouse to be positioned supine underneath the surface coil, compared to the more natural prone position used for the RT cardiac coil array. Cardiac images of a mid-ventricular short axis view obtained with both scan protocols and for each coil are shown in Figure 1. For the standard imaging protocol SNR was significantly increased when using the cryogenic probe (SNR = 122 ±2 (mean ±std), Fig. 1a) versus RT coil (SNR = 31 ±4, Fig. 1d) resulting in an SNR gain of 4.0 ±0.6. The increased SNR was exploited in the high spatial resolution protocol (Fig. 1b). This approach yielded an SNR of 27 ±4 for the cryogenic probe which meets that of the RT coil when using the low spatial resolution standard protocol. In comparison images acquired with the high spatial resolution protocol using the RT coil showed an SNR as low as 8 ±1 (SNR gain with CP = 3.5 ±0.1) which compromises the detection and tracking of endo- and epicardial borders (Fig. 1e). Besides an enhanced overall image quality, the images derived from the high spatial resolution protocol revealed improved border sharpness between myocardium and blood in the ventricular cavities. The visualization of subtle anatomic structures was found to be enhanced, with ventricular trabeculae being much better delineated compared to the standard protocol. Also, the thin myocardium of the right ventricle was found to be very well delineated from the blood.

Discussion and Conclusions: This work demonstrates the feasibility of high spatial resolution functional cardiac imaging in mice using a cryogenic RF coil. No deterioration in image quality due to the transceive B_1 characteristic of the cryogenic probe were observed. The SNR gain inherent to the cryogenic probe was translated into a four-fold improved in-plane spatial resolution while maintaining an acceptable acquisition time for whole heart coverage and an SNR comparable to the standard low spatial resolution protocol. Our results suggest that the use of a cryogenic RF coil could not only improve the accuracy of left ventricular function and morphology assessment, but also affords chamber quantification of the right ventricle. This is of profound importance for the assessment of right ventricular morphology and function with the ultimate goal to study sex-specific effects of progression and regression of hypertension induced myocardial hypertrophy, since remodelling and myocardial injury are not restricted to the left ventricle. Consequently, we anticipate to extend our studies to pharmacologically (Ang II), exercise (VCR) and transverse aortic constriction (TAC) induced models of myocardial hypertrophy to make further use of the proposed CMR approach.

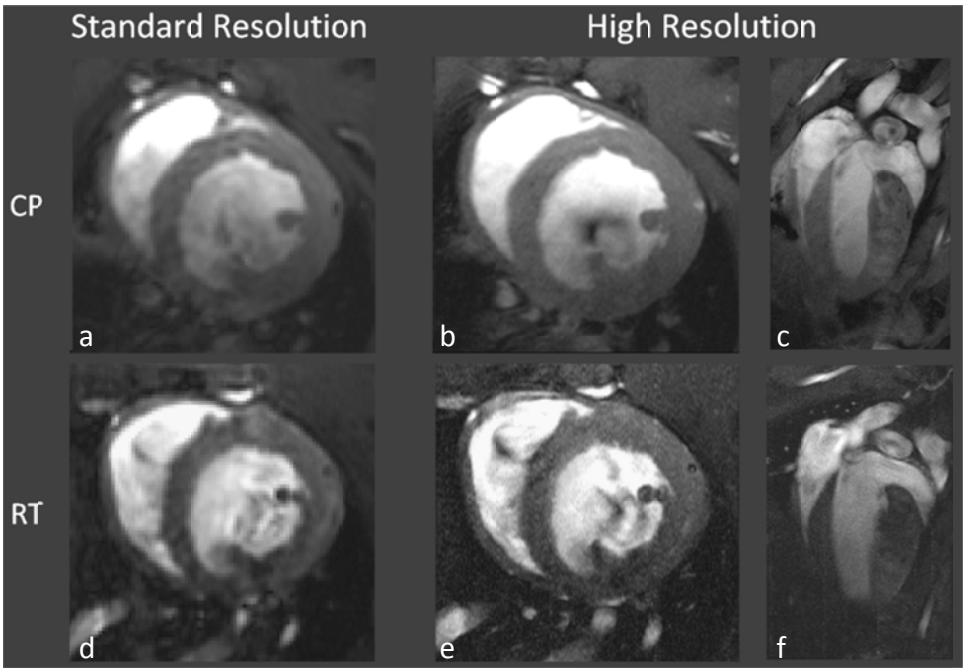

Fig.1) Short axis (a,b,d,e) and long axis (c,f) view of a mouse heart, acquired with the cryogenic probe coil (a,b,c) and the RT coil (d,e,f). Left: Images acquired using the standard protocol. Right: Images acquired using the high resolution protocol.

References: [1] Ratering D et al., MRM 2008. [2] Baltes C et al., NMR Biomed 2009. [3] Baltes C et al., NMR Biomed 2010. [4] Heijman E et al., NMR Biomed 2007. [5] Bovens SM et al., NMR Biomed 2011.