Towards clinical cardiac MR at 7.0 T: Early experience with black blood RARE imaging in patients with hypertrophic cardiomyopathy

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Target audience: This work is of interest for basic MR researchers, imaging scientists, clinical scientists, radiologists and cardiologists.

Purpose: Hypertrophic cardiomyopathy (HCM) is a genetic cardiac disease affecting about 0.2% in the general population. Myocardial disarray with myocyte hypertrophy and fibrosis are histopathologic hallmarks of HCM. Assessment of myocardial thickness demands non-invasive imaging – the forte of cardiac magnetic resonance (CMR). In current clinical CMR black blood fast spin-echo (FSE) or RARE techniques are commonly used for anatomical and morphological imaging of the heart [1-3]. Transfer of RARE based black blood imaging to 7.0 T is of high relevance for advancing the capabilities of probing cardiac morphology through sub-millimeter in-plane spatial resolution imaging afforded by the SNR gain inherent to ultrahigh fields [4]. Recognizing the opportunities and challenges of cardiac RARE imaging at 7.0 T this feasibility study examines the clinical applicability of myocardial black blood imaging at 7.0 T in healthy volunteers and in patients with HCM.

Methods: CMR exams of 14 healthy volunteers (mean age: 55 (range 24-71 years), mean BMI: 26 kg/m² (range 21-36 kg/m²)) and 13 HCM patients (mean age: 55 years (range 25-71 years), mean BMI: 26 kg/m² (range 23-36 kg/m²)) were performed. A 7.0 T whole body MR system (Magnetom, Siemens Healthcare, Erlangen, Germany) was employed in conjunction with a 16 channel RF coil array tailored for cardiac imaging [5]. Written informed consent was received from every subject prior to the exam. High resolution black blood imaging of 4 chamber views was performed using a RARE technique (TR = 1 R-R interval, TE = 45 ms, echo spacing (ESP) = 6.5 ms, echo train length = 12, spatial resolution = (1.2 x 1.2 x 5.0) mm^3, nominal flip angle = 180°). The data acquisition window for breath-hold RARE imaging was placed in end-diastole. For comparison standard 2D CINE FLASH imaging was conducted (TR = 5.7 ms, TE = 2.7 ms, spatial resolution = (1.4 x 1.4 x 4.0) mm^3, nominal flip angle = 32°). For cardiac gating acoustic triggering using an MR stethoscope (easyACT, MRI.TOOLS GmbH, Berlin, Germany) and pulse oximetry were employed.

Results: RARE imaging of a four-chamber view was performed in healthy volunteers and HCM patients. Exemplary results are presented in Figure 1 for a healthy subject and two HCM patients (healthy subject: 55 years, BMI = 29.3 kg/m^2, 62 bpm; patient 1: 66 years, BMI = 22.9 kg/m^2, 62 bpm; patient 2: 47 years, BMI = 24.6 kg/m^2, 64 bpm). 2D CINE FLASH images derived from the patients demonstrate the septal hypertrophy of the left ventricle, a typical feature of HCM. The atypical apical insertion of the hypertrophied papillary muscles can be demonstrated nicely. The corresponding black blood images afforded the visualization of regional hypertrophy but underscored the challenges of cardiac RARE imaging at 7.0 T. Since blood flow is parallel to the four chamber view of the heart blood signal contributions remained in regions with slow blood flow, in particular in regions close to the apex. Motion artifacts present another challenge since patient capabilities for breath-holding are significantly inferior versus healthy subjects. Notwithstanding these challenges the good delineation of the myocardium from the blood pool can be appreciated in Fig. 1 for regions with sufficient B_1^+ homogeneity. In apical regions subtle trabecular structures can be seen, while signal of slow flowing blood, which is trapped in between the trabeculae, is not suppressed entirely such that it appears hyperintense. Despite the slow blood artefact the 2D CINE FLASH based diagnostic conclusions obtained for the HCM patients shown in Fig. 1 could be confirmed. However, in HCM patients the septum was clearly delineated in only 15% of the subjects. For the remaining subjects, RARE imaging revealed severe artifacts due to motion or cardiac arrhythmia induced mis-triggering. Unlike RARE imaging, standard CINE FLASH imaging provided diagnostic image quality for all subjects.

Discussion: *En route* to clinical cardiac MR at 7.0 T transfer of RARE imaging – which is very well established for CMR at 1.5 T and 3.0 T – to 7.0 T is of relevance for advancing the capabilities of UHF-CMR with the ultimate goal to foster explorations into cardiac morphology, myocardial microstructure and myocardial tissue characterization. Our preliminary results obtained for HCM patients provide encouragement but B_1^+ non-uniformities, SAR constraints, imperfect blood suppression along with fat suppression deficits remain a major concern. The refinement of black blood preparation modules – including double inversion recovery preparation – tailored for 7.0 T is anticipated to further RARE image quality at 7.0 T. Here a modest diffusion weighting could provide a valuable alternative for spoiling remaining signal induced by slow flowing blood. Our preliminary data also indicate that the dynamic range of RARE image contrast at 7.0 T is dominated by subcutaneous fat signal which requires further efforts into fat suppression techniques. Alternatively, reduced field of view acquisition can be exploited to exclude subcutaneous fat of the chest wall from the field of view.

Conclusion: Our preliminary results underscore that cardiac black blood imaging at 7.0 T remains challenging in in patients. The main obstacles causing suboptimal image quality identified in this early patient study were motion induced artifacts due to non-compliance with the breath-hold regime, mis-triggering due to cardiac arrhythmia and acquisition window timing within the cardiac cycle. Further developments are essential to translate the benefits of high resolution black blood imaging at 7.0 T into a clinical setting including heart rate adapted triggering, faster acquisition schemes supported by inter-echo time shortening and improved transmission field uniformity.

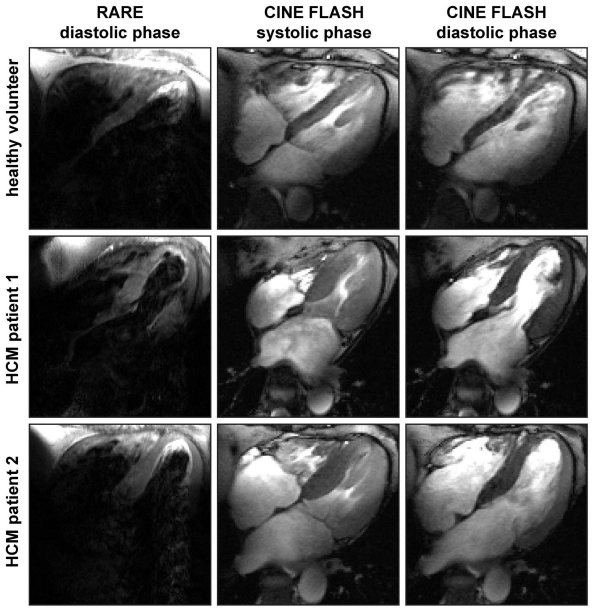

Figure 1: Four chamber views of the heart for a healthy volunteer (**top**) and two HCM patients **(center/bottom)** for RARE black blood imaging (**left**) and standard FLASH CINE imaging in systolic (**center**) and diastolic phase (**right**) at 7.0T.

References: [1] Simonetti et al. (1996) Radiology 199(1):49, [2] Hundley et al. (2010) JACC 55(23):2614, [3] Krishnamurthy et al. (2014) Cardiovasc Diagn Ther 4(2):104, [4] Fuchs et al., Proc. ISMRM 21, 2013:1413, [5] Thalhammer et al. (2012) JMRI 36(4):847.