Coronary MR Angiography at 7.0 Tesla Using 3D Fat-Water Separated Imaging and a 8 Channel Array of Bowtie Dipole Transceivers: A Feasibility Study

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TARGET AUDIENCE: This work is of interest for clinicians, clinical scientists interested in coronary MR angiography and for basic researchers and engineers, who are working in the field of high and ultrahigh field MR.

PURPOSE: Coronary MR angiography (CMRA) is of proven value for non-invasive assessment of coronary arteries. For CMRA at 1.5 T 3D SSFP techniques are primarily used. The issue of off-resonance sensitivity of SSFP remains a significant concern for CMRA at higher field strengths. This has prompted a return to fast gradient-echo imaging (FGRE) techniques for CMRA at 3.0 T. SSFP and FGRE based CMRA share in common that preparatory fat saturation is applied to increase the lumen/myocardium contrast. Notwithstanding its success large static field variations at higher field strengths may cause non-uniform and imperfect fat-suppression over the target region; an effect which bears the risk to obscure the delineation of coronary arteries. This practical impediment is pronounced at 7.0 T although preliminary reports suggest that CMRA quality obtained at 7.0 T may already begin to approach that of 3.0 T CMRA at this early stage of the development process [1, 2]. Multi-echo Dixon approaches utilizing iterative decomposition have been shown to provide robust fat-water separation even in the presence of large field inhomogeneities [3]. Realizing the challenges and opportunities of such an approach in equal measure this work examines the feasibility of whole heart coverage CMRA at 7.0 T using cardiac-triggered navigator-gated 3D FGRE. Fat suppression is achieved by fat-water separated imaging to provide enhanced visualization of coronary arteries. For this purpose, an interleaved multi echo approach is applied. A sixteen channel transceiver array tailored for cardiac MRI that uses bowtie antenna is employed. Bowtie antenna generate E- and H fields such that the Poynting vector is oriented perpendicular to the main axis of the dipole antenna which renders radiative elements being ideal candidates for CMRA at 7.0 Tesla.

METHODS: Volunteer studies were performed on a 7.0T whole body MR system (Magnetom, Siemens Healthcare, Erlangen, Germany). A coil array consisting of 8 dipole elements distributed in a ring of eight elements around the upper torso (four elements posterior, four elements anterior) was used for signal transmission and reception. B_1 field was shaped based on electro-magnetic field simulations. No volunteer specific RF shimming was applied. For CMRA a 3D navigator-gated multi-echo spoiled gradient echo technique (in-plane resolution= (1.4x1.4) mm^2, acquired slice thickness=2.5 mm, nominal flip angle=25°, bandwidth= 977 Hz/pixel) was employed. A multi-shot approach was used to reduce the effective echo spacing to 0.25 ms, which resulted in equidistant echo times ranging from 2.37 ms to 3.37 ms. The acquisition was placed at end-diastole using acoustic cardiac triggering (easyACT, MRI.TOOLS GmbH, Berlin, Germany). B_0 Shimming was optimized using a cubic volume encompassing the whole heart. Water-fat separated image reconstruction used a multi-echo Dixon like technique based on the VARPRO formulation with graphcut optimization [3] to jointly estimate the water and fat.

RESULTS: 2D CINE FGRE imaging at 7.0 T using the 8 channel dipole antenna transceiver array provided rather uniform signal intensity across the heart as demonstrated in Fig. 1. For a four chamber view no obvious B_1^+-inhomogeneities are visible across the target region although no volunteer specific dynamic RF shimming has been applied. This quality enabled 3D CMRA at 7.0 T using fat-water separated imaging. Our preliminary results show that fat and water were correctly classified as demonstrated in Fig. 2-4 for the left main coronary artery (LAD). Decent fat-water separation was achieved across the entire field of view. Fat suppression was estimated in water regions to be greater than 8:1 across the FOV. SNR of the left ventricular myocardium was in the range 100-200.

DISCUSSION: The use of bowtie dipole antenna affords substantial improvements in B_1 uniformity which is beneficial if not essential for fat-water separated coronary artery imaging at 7.0 T. Our preliminary results are heartening since numerical EMF simulations using the human voxel model "DUKE" were employed for B_1^+ optimization rather than using time consuming patient specific transmission field optimization. Further improvements in the RF coil design used are expected to enhance the SNR and uniformity of contrast between blood and myocardium. Fat-water separated CMRA at 7.0 T has been demonstrated using a multi-echo Dixon like approach providing excellent fat water separation. This approach holds the promise to address some of the RF power deposition constraints which come with conventional saturation recovery based fat saturation techniques that make use of large flip angles. Arguably, fat water separated CMRA at 7T has unique challenges due to the increased B_0 peak-to-peak variation, T_2^* dephasing, and larger chemical shift. A multishot approach was used to achieve shorter echo spacing, and decreased slice thickness was applied to reduce T_2^* losses due to intra-voxel dephasing. Fat suppression is believed to be limited by eddy currents and is being investigated. In the current results, precalibrated spectra were based on measurement at lower field strength; calibration at 7.0 T is planned.

CONCLUSION: Fat-water separated coronary MRA is feasibly at 7.0 T. A recognized limitation of this feasibility study is its assessment of a limited number of healthy subjects, but this mandatory precursor was essential before extra variances due to gender and/or pathophysiological conditions are introduced.

References:

[1] van Elderen S.G., et al., Radiology (2010) 257:254 [2] van Elderen S.G., et al., Magn Reson Med (2009) 62:1379 [3] Hernando D., et al., Magn Reson Med (2010) 63:79

Fig. 1: 4 chamber view CINE gradient echo image. Signal intensity is uniform across the heart and no obvious B_1^+-inhomogeneities are visible.

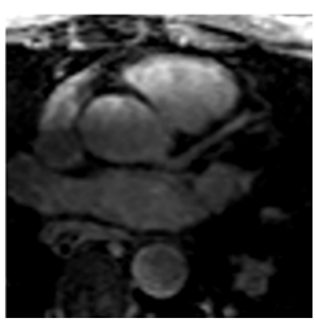

Fig. 2: Water-only image of the left ascending coronary atery. Fat supression works well across the heart

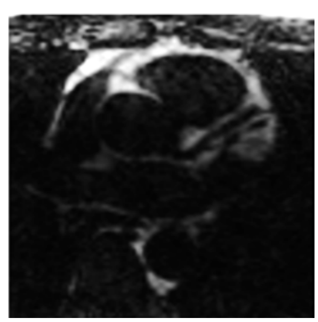

Fig. 3: Corresponding fat-only image. The position of the LAD is visible in the epicardial fat.

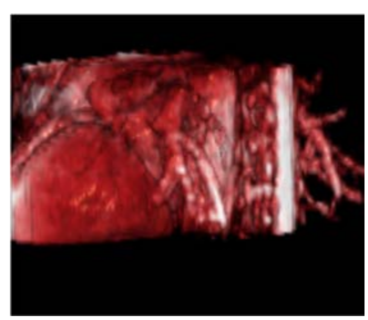

Fig. 4: 3D reconstruction the 3D water-only dataset, visualizing the quality of fat suppression across the heart.