Towards Myocardial T_2^* Mapping at 7.0 T: Assessment and Implications of Static Magnetic Fields Variations

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TARGET AUDIENCE This work is of interest for clinicians, clinical scientists, basic researchers and engineers interested in susceptibility weighted cardiac MR imaging or other imaging applications which require a uniform B_0 distribution at ultrahigh magnetic fields.

PURPOSE Emerging cardiovascular magnetic resonance (CMR) imaging applications include T_2^* relaxation sensitized techniques, which are increasingly used in basic research and (pre)clinical imaging. The linear relationship between magnetic field strength and microscopic susceptibility renders it conceptually appealing to pursue myocardial T_2^* mapping at ultrahigh magnetic field strengths. For T_2^* sensitive imaging techniques it is important to reduce static macroscopic field inhomogeneities across the heart to make susceptibility weighted imaging dominated by microscopic B_0 susceptibility gradients, rather than by macroscopic B_0 field inhomogeneities. For this reason, this work carefully examines B_0 field distributions across the heart and reports implications for myocardial T_2^* mapping at 7.0T.

METHODS Volunteer experiments were performed on a 7.0T whole body MR system (Magnetom, Siemens Healthcare, Erlangen, Germany). First and second order shim currents were calculated based on cardiac triggered B_0 field map. The B_0 field map was obtained as an axial stack covering the whole heart (Fig. 1a) with a multi-echo gradient echo sequence (T_E=2.04ms and 4.08ms, matrix size=96x72, 18 slices) within a single breathhold. The shim volume was adjusted to cover the ventricles and the atria in the 4 chamber view and was adjusted along a stack of short axis views of the heart (Fig 1b/c). Standard global B_0 shim and volume selective shim were analyzed via a higher resolution field map, which was was obtained for short axis and 4 chamber views. The imaging parameters for this 2D cardiac triggered multi echo gradient echo were: in-plane resolution=1.4x1.4mm², slice thickness=2.5mm, nominal flip angle=25°, TEs=1.87, 2.12, 2.37, and 2.62ms. The field map was reconstructed via the VARPRO formulation with graphcut optimization [1]. T_2^* mapping was conducted using equidistant T_Es ranging from 2.04 to 10.20ms and a voxel size of 1.4x1.4x4mm³

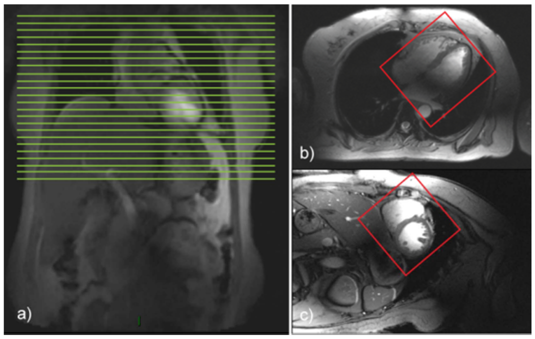

***Figure 1: a)** Planning of the axial field map used for B_0 shimming. Placement of a cubic shim volume in **b)** a 4 chamber view and in **c)** a short axis view of the heart.*

RESULTS Figure 2 depicts B_0 maps (Fig. 2a) together with B_0 profiles across the heart (Fig. 2b) and B_0 histograms (Fig. 2c) obtained prior and after volume selective shimming for a four chamber view. The B_0 field maps following global shimming showed a mean peak-to-peak field difference of approximately 300Hz across the long axis of the ventricles. After volume selective shimming, a mean peak-to-peak B_0 difference of approximately 80Hz was found for the same region. Along the short axis of the heart a peak-to-peak B_0 difference of approximately 160Hz was observed before volume selective shimming. After volume selective shimming the peak-to-peak B_0 difference was reduced to 80Hz. The strongest susceptibility gradient of 14Hz/pixel was found for the inferior segment of the heart indicated by the arrows in the T_2^* map shown in Fig. 2d. A maximum in-plane field gradient of approximately 14Hz/mm (through-plane approximately 60Hz/voxel for a 4mm slice thickness) was observed at the myocardium/epicardial fat/lung interface of the inferior and inferolateral segment as indicated by the B_0 maps and frequency profiles shown in Figure 2 a/b. This local B_0 gradient translates into a phase loss of approximately 60% at the maximum echo time of T_E=20ms used for T_2^*mapping. However, the field gradient at the myocardium/epicardial fat/lung interface is much more pronounced versus the through-plane field gradient obtained for the left and right ventricle, which showed a mean of 3Hz/mm as indicated in Figure 2b. For myocardial anterior, anterolateral and inferoseptal segments a mean in-plane B_0 gradient of approximately 3Hz/mm was obtained which translates into an through-plane B_0 dispersion of approximately 12Hz/voxel for a 4mm slice thickness. This B_0 gradient implies that macroscopic intravoxel dephasing effects are of minor effect for the T_E range used for T_2^*mapping. The T_2^* maps acquired after volume selective shimming showed reduced susceptibility artifacts and a more uniform distribution of T_2^* values across the myocardium. Please also note the difference in T_2^* between left and right ventricular blood pool.

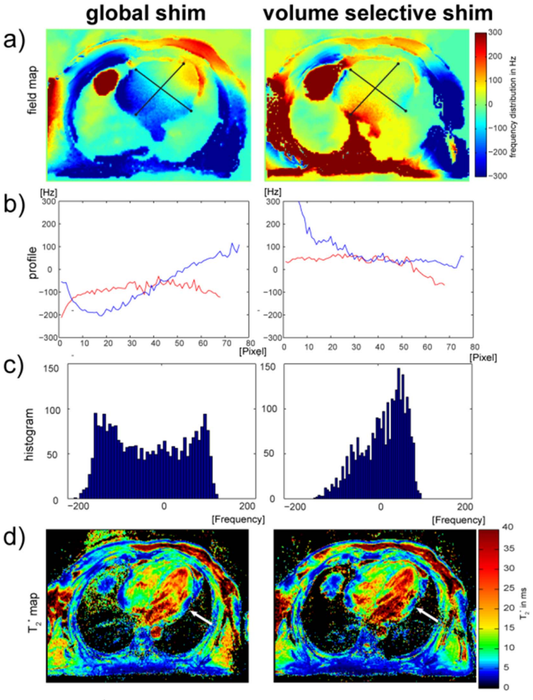

***Figure 2: a)** B_0 field map before and after volume selective shimming **b)** profile of frequency distribution along the long and short axis of the heart c) histogram of frequency distribution over left ventricle **d)** corresponding T_2^* map generated before and after volume selective shimming.*

DISCUSSION Our B_0 mapping results suggest that a reasonable B_0 uniformity across the heart and the left ventricle can be achieved at 7.0T which is embodied by a mean through-plane gradient of 3Hz/mm across the left ventricle. The frequency shift across the heart observed at 7.0T compares well with previous 3.0T studies which reported a peak-to-peak off-resonance variation of 121±31Hz using localized linear and second-order shimming [2]. The use of an enhanced locally optimized shim algorithm, which is tailored to the geometry of the heart, afforded a reduction of the peak-to-peak frequency variation over the heart from 235Hz to 86Hz at 3.0T [3]. Our studies suggest that third-order and even higher order shims might help to further enhance B_0 uniformity across the across the heart at 7.0T. Obviously, another approach to further reduce the residual impact of through-plane gradients and intra-voxel dephasing B_0 gradients is the use of even thinner slices and the reduction in voxel size. To meet this goal we pushed the envelope by using a slice thickness as thin as 2.5mm together with an in-plane resolution of 1.1x1.1mm² for T_2^*mapping. This slice thickness and in-plane resolution is afforded by the SNR advantage inherent to 7.0T. The corresponding voxel size is by a factor of five smaller than commonly used for T_2^* mapping at 1.5T and 3.0T.

CONCLUSION Our results underscore the challenges of myocardial T_2^* weighted imaging at 7.0T due to the propensity to macroscopic susceptibility artifacts and T_2^* shortening, but demonstrate that these issues can be offset by using tailored shimming techniques.

REFERENCES: [1] Hernando et al (2010) Magn Reson Med 63:79 [2] Schaer et al (2004) Magn Reson Med 51:799 [3] Schaer et al (2010) Magn Reson Med 63: 419.