Whole-Heart T1 and Extracellular Volume Fraction Mapping with 6 Heartbeats

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Target audience: Scientists interested in quantifying myocardial fibrosis in the whole-heart, using a rapid T1-mapping MRI method.

Purpose: Cardiac MR with late gadolinium enhancement (LGE) is limited in its accuracy for absolute quantification of myocardial fibrosis, as it relies on the difference in relative signal intensity between fibrotic and normal myocardium; such local differences may not exist if the fibrotic process is diffuse. Compared to LGE, T1-mapping and the use of T1 changes from contrast enhancement for extracellular volume (ECV) quantification are clinically promising techniques[1,2]. However, whole-heart T1-mapping is rarely performed in clinical practice, due to the associated time-consuming data acquisition (e.g., ~15-20s for one 2D T1 map[3]). Instead, it is usually performed at a single mid-ventricular level; this can lead to sampling error when the fibrotic process is not homogenous. In this study, we present a method for rapid whole-heart T1-mapping in a single breath-hold of, e.g., 6 heartbeats (typically, 5-7 seconds for total 9 T1 maps), for the quantitative assessment of myocardial fibrosis.

Methods: Whole-heart T1-mapping was performed using a 1.5T MRI scanner (Avanto, Siemens Healthcare). We modified a turboFLASH pulse sequence[5] to acquire 9 T1-weighted (T1w) images within 3 heartbeats at different levels, with increasing sequential time delays TD = 200ms (for slices 1,4,7), 200ms + TR (for slices 2,5,8) and 200ms + 2xTR (for slices 3,6,9), after a non-selective saturation pulse (Fig.1). In the first three heartbeats, 9 corresponding proton density-weighted (PDw) images are acquired, in order to correct for the B1- and the unknown equilibrium magnetization, and normalize the signal. Centric k-space acquisition ordering was used to minimize the sensitivity to inflow effects and to reduce the sensitivity to B1+ profile after image normalization[4]. Post-contrast T1 maps were acquired 37 minutes after contrast injection (0.15mmol/kg of gadolinium-DTPA). Using the Bloch equation, T1 is obtained from the normalized signal, S_{norm} (= S_{T1w}/S_{PDw}), and TD; T1 = -TD/ln(1-S_{norm}).

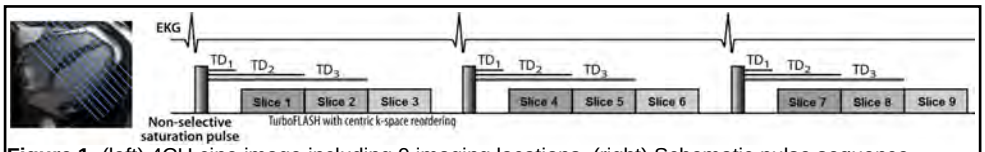

Figure 1. (left) 4CH cine image including 9 imaging locations. (right) Schematic pulse sequence diagram of the whole-heart T1-mapping method.

Results: Figure 2 shows the results from two representative subjects; normal control (60 yrs; male; no focal LGE) and one patient with hypertrophic cardiomyopathy (56 yrs; male; maximum myocardial thickness = 15 mm; no focal LGE). Total scan time for these representative subjects was 5.4 - 6.2s for 9 slice locations. For the control and patient, pre-contrast myocardial T1 values were 1143 ± 193 ms and 1421 ± 158 ms, and ECV values (assuming hematocrit of 0.47 for both subjects) were 0.22 ± 0.06 and 0.21 ± 0.04, respectively. Although there is no focal LGE, this patient shows a higher pre-contrast T1 than in the control (typically, T1 of ~1s at 1.5T for normal controls), suggesting a higher degree of diffuse myocardial fibrosis.

Discussion: While conventional T1-mapping methods are very time-consuming for routine clinical application, our new approach can be used to perform whole-heart T1-mapping and ECV mapping within 6 heartbeats. Our preliminary results show a higher pre-contrast T1 in the patient, suggesting a higher degree of diffuse myocardial fibrosis. For accurate ECV calculation, blood samples for individuals should be drawn during MRI for hematocrit calculation, which was not included in this study.

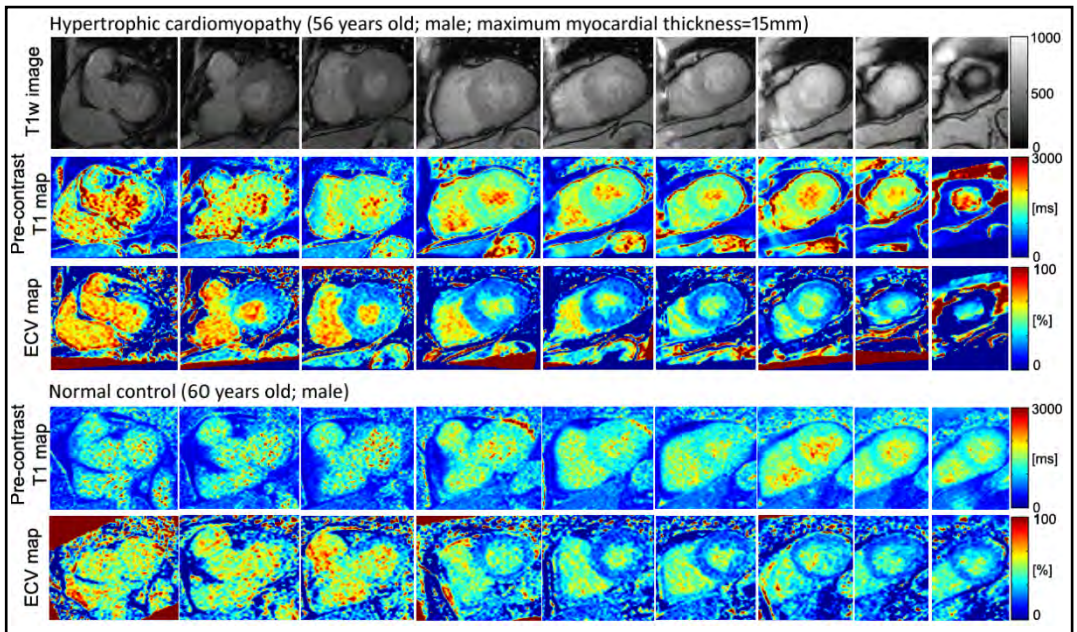

Figure 2. (Top) HCM patient: from top to bottom, T1w images and corresponding pre-contrast T1 and ECV maps at different levels. (Bottom) normal control: pre-contrast T1 and ECV maps at different levels.

Conclusion: Our study shows the potential clinical utility of T1-mapping for quantifying whole-heart fibrosis. Due to its short acquisition time, it is likely to perform well in patients with cardiac disease-related problems, including arrhythmia or difficulty with breath-holding. Better characterizing whole-heart fibrosis may allow for more accurate and earlier diagnosis. Further studies are warranted.

References: [1] Messroghli et al. MRM 58; 34 (2007). [2] Puntmann et al. JACC 6; 475 (2013). [3] Messroghli, et al. Radiology 238; 1004 (2006). [4] Breton, et al. ISMRM 2010. [5] Breton, et al. JMRI 34; 676 (2011).