Myocardial T2 mapping with respiratory navigator and non-rigid registration: comparison of motion compensation techniques

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Introduction: Recently, evidence was shown that T2 quantification may be superior to T2 weighted (T2W) imaging for detecting myocardial edema [1, 2]. However, pixel-wise T2 mapping of myocardium is sensitive to misregistration caused by inadequate breath-hold, inconsistent cardiac rhythm or subject motion; the misregistered pixels from multi-echo images may represent different tissues, giving incorrect T2 values. Motion-compensation techniques try to overcome this problem. In this work, we present a T2 mapping sequence that utilizes two complementary motion-compensation techniques: respiratory navigator and non-rigid registration. We hypothesize that the use of non-rigid registration significantly reduces residual motion-induced variation in T2 and that the combined use of registration and navigator enable free-breathing acquisition of T2 maps with results comparable to those of breath-hold acquisitions.

Materials and Methods: The basic T2 mapping sequence has been described in our previous work [1]. Briefly, T2 maps were generated using mono-exponential, log-transformed linear least-squares fit to signal intensities at each pixel of three T2-prepared (T2p) SSFP images; the T2p was spatially non-selective [3] and the SSFP data acquisition was performed in a single-shot fashion. The other imaging parameters are listed in Table 1.

Two new features were incorporated into this sequence: respiratory navigator and non-rigid registration. The respiratory navigator accepted an image for further processing (registration and T2 mapping) only if the diaphragm position was within an acceptance window of 8 mm, chosen as a good balance between imaging time and motion sensitivity. Motion correction was performed using a fast non-rigid registration algorithm [4] which aligned all T2prep frames to the center frame (T2p=24 ms). Finally, pixel-wise T2 fitting generated color-coded T2 maps inline; the entire post-processing was unsupervised and typical processing time was less than 1 s.

Mid-SAX and HLA images were acquired in 5 healthy subjects under three conditions: breath-hold (BH), free-breathing without navigator (FB), and free breathing with respiratory navigator (FB-Nav). For each case, T2 maps were generated both with and without non-rigid registration, giving a total of 6 maps per slice. The range of T2 values was 0 – 150 ms; any value outside of this range was set to 150 ms. Myocardial contours were drawn in the center frame that was not modified by the registration algorithm; the contours were then transferred to the other images and to the T2 map. T2 variability (σ_{T2}) across the entire myocardium (except Apex for HLA) was used as a measure of motion-sensitivity of T2 maps. σ_{T2} from the six sets were compared using non-parametric tests.

Results: Mean T2 in breath-hold acquisition was not different before and after registration (51.4 ms vs 52.2 ms; p = 0.13). For free-breathing acquisition without navigator, registration significantly reduced σ_{T2} in both SAX and HLA views ($p < 0.05$); Figure 1 shows the effect of motion on T2 map in SAX view of a subject. The difference in σ_{T2} with and without registration was not significant for breath-hold (p=0.21) and navigator acquisitions (p=0.1). After registration, the variability in all 3 acquisitions was similar (p-value = not significant). Figure 2 summarizes the data for SAX view. In HLA of two subjects and SAX of one subject, there was high T2 variability in the navigator acquisition; this was corrected by registration (Figure 3).

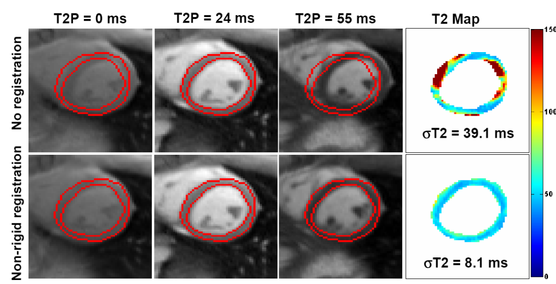

Figure 1 (color). Effect of non-rigid registration on T2 map acquired in a subject without breath-hold or navigator gating. Before registration, the contour, drawn in T2p=24 ms image, encloses mis-registered pixels with high T2 (σT2 = 39.1 ms); after registration, the contour contains pixels with uniform T2 (σT2 = 8.1 ms).

Discussion: The use of registration algorithm did not alter myocardial T2 values, yet reduced the motion-induced T2 variability in free-breathing acquisitions with and without the use of navigator, thus increasing precision without compromising on accuracy. It must be noted, however, that the registration algorithm corrects for in-plane motion only, while navigator gating helps to ensure reproducible position of the heart in all directions. The effects of through-plane motion were not adequately addressed by this experiment in normal subjects where the T2 is expected to be uniform throughout the myocardium. We found that navigator gating alone was insufficient for T2 mapping in some cases (Figure 3). The use of non-rigid registration provided additional motion compensation that reduced T2 variability. When combined, these two techniques provide complementary motion-compensation, with navigator providing reproducible positioning of the heart in all directions, and registration correcting for any residual in-plane motion; this approach permits free-breathing acquisition of T2 maps and may enable 3D T2 mapping in future.

Conclusion: We have demonstrated a fully-automatic and reliable free-breathing T2 mapping sequence that provides two complementary motion-compensation schemes: respiratory navigator and non-rigid registration. Future work will focus on clinical validation and 3D T2 maps.

References: [1] Giri et. al. JCMR 2009. 11:56. [2] Verhaert et al. JACC: Cardiovascular Imaging. *(In press)*. [3] Brittain et. al. MRM. 1995. 33:689. [4]. Xue et al. MICCAI 2008, Part II, LNCS 5242, pp. 35–43.

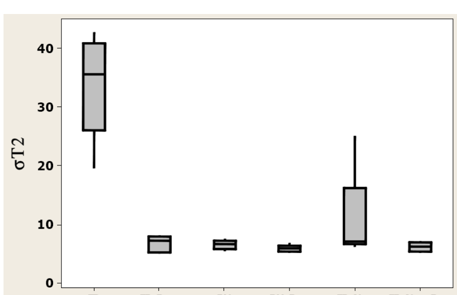

Figure 2. Comparison of T2 variability with different acquisition and post-processing schemes in 5 subjects. Note the high variability of T2 when acquired in free breathing without navigator or non-rigid registration algorithm. FB = Free breathing; BH = Breath-hold; Reg = non-rigid registration; Nav = respiratory navigator.

Table 1. Imaging parameters

Parameter name	Value
Number of T2Preps	3
T2P times	0 (no prep), 24, 55 ms
Acquisition window	~ 150 ms
Acquisition mode	Single shot
Image Matrix	130 x 160
Slice thickness	8 mm
Parallel acquisition/ acceleration/reference lines	GRAPPA/2/24
Repetition time	3 RR intervals
Flip angle	70 degrees
Field strength	1.5 T

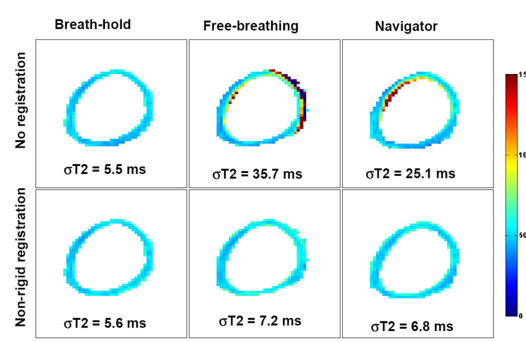

Figure 3 (color). T2 maps with different acquisition and post-processing strategies in one subject. There is high T2 variability in free-breathing acquisition without registration. Also note that navigator alone did not provide sufficient motion compensation.