Ungated, Free-breathing Arrhythmia-Insensitive-Rapid (AIR) Cardiac T_1 mapping with Motion Corrected Registration

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Introduction: Most cardiac T1 mapping pulse sequences are conducted with ECG-gating and breath-holding to acquire multiple T1-weighted images for calculation of a pixel-by-pixel T1 map [1-3]. While this approach works well in patients with sinus rhythm and good breath-holding, it leads to corrupted T1 maps in patients with arrhythmia and/or poor breath-holding. One approach to address this problem is to perform motion-correcting registration during post-processing. One such software is Advanced Normalization Tools (ANTs)[4], which is based on diffeomorphic deformation, having the advantages of open source implementations (http://stnava.github.io/ANTs) and adaptable for cardiac MR images [5]. In this work, we sought to evaluate the performance of ungated, free-breathing arrhythmia-insensitive-rapid (AIR) cardiac T1 mapping [3] with ANTs registration as compared to ECG-gated breath-hold AIR as the reference.

Methods: *(Human Experiment)* We imaged 11 patients with atrial fibrillation (mean age = 60.4 ± 15.1 yrs) before and after administration of contrast agent (Gd-BOPTA, 0.15 mmol/kg) on a 3T MRI system (Verio, Siemens). For each subject, we performed ECG-gated breath-hold AIR (control) and ungated, free-breathing AIR acquisitions in a mid-ventricular short-axis plane. The pulse sequence order was randomized to minimize potential bias. We note that ECG-gated breath-hold AIR acquires one proton density image and one T1-weighted image in scan time of 2-3 heart beats. Ungated, free-breathing AIR acquires one proton density and 9 T1-weighted images in scan time of 8.3 s. Both AIR protocols used: FOV = 360 mm x 270 mm, slice thickness = 8 mm, acquisition matrix = 192 x 144 (PE), TE = 1.1 ms, TR = 2.7 ms, receiver bandwidth = 930 Hz/pixel, centric-pair k-space ordering [6], temporal resolution = 217 ms, saturation-recovery time delay (TD) = 600 ms, flip angle = 55˚, acceleration factor (GRAPPA) = 1.8. *(Image Analysis)* Pixel-by-pixel T1 maps were generated as previously described [3]. For ungated, free-breathing AIR, we applied ANTs to generate all nine T1 maps. After visual inspection, we used the best registration results to compare with ECG-gated breath-hold AIR results. Contours of myocardium and left ventricular blood pool were manually drawn to average T1 values. *(Statistical Analysis)* We calculated the mean T1 values over subjects for each of four tissue types (i.e., native myocardium, native blood, post-contrast myocardium, and post-contrast blood) and compared the mean T1 values between ECG-gated breath-hold and ungated free-breathing AIR using paired t-test ($p < 0.05$ considered significant).

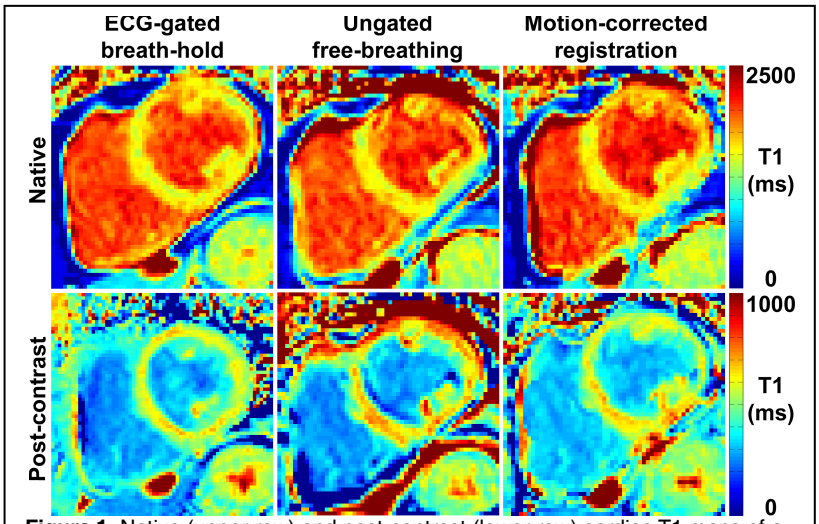

Figure 1. Native (upper row) and post-contrast (lower row) cardiac T1 maps of a patient acquired by ECG-gated breath-hold (left column), ungated free-breathing (middle column), and motion-corrected registration (right column).

Results: Figure 1 shows native and post-contrast cardiac T1 maps of a patient acquired by ECG-gated breath-holding and ungated, free-breathing, as well as motion corrected T1 maps with ANTs. While the mean T1 values were significantly different between ECG-gated breath-hold and ungated, free-breathing AIR acquisitions ($p < 0.05$), the percent difference between them was less than 5% for all four tissue types, suggesting clinically negligible differences (Table 1).

Table 1. Mean myocardial and blood T1 measurements before and after administration of contrast agent over 11 patients. T1 values represent mean ± standard deviation.

Tissue type		ECG-gated breath-hold T1 (ms)	Registered T1 (ms)	Percent difference (%)	*p*-value
Native	Myocardium	1464 ± 58	1501 ± 56	2.6	0.001
	Blood	2036 ± 161	1966 ±174	-3.4	0.02
Post-contrast	Myocardium	694 ± 46	711 ± 63	2.3	0.02
	Blood	393 ± 62	407 ± 74	3.1	0.03

Conclusions: This study demonstrates the feasibility of diffeomorphic deformation to correct registration errors in the context of ungated free-breathing AIR cardiac T1 mapping. A future study is warranted to evaluate fully the clinical utility of ungated, free-breathing AIR cardiac T1 mapping with motion correction.

References: [1] Messroghli DR et al., *MRM* 2004;52:141-146. [2] Chow K et al., *MRM* 2014;71:2082-2095. [3] Fitts M et al., *MRM* 2013;70:1274-82. [4] Avants BB et al., *Med Image Anal.* 2008;12(1):26–41. [5] Adluru G et al., Proc. SPIE8858, 2013;doi:10.1117/12.2024046. [6] Bieri O et al., *MRM* 2005;54:129–137. **Funding:** NIH (HL116895-01A1), American Heart Association (14GRNT18350028).