Wideband Arrhythmia-Insensitive-Rapid (AIR) Cardiac T_1 mapping Pulse Sequence for suppressing Image Artifacts induced by ICD

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Introduction: Cardiac T_1 mapping is emerging as promising method for assessment of diffuse cardiac fibrosis in heart failure (HF) patients with non-ischemic cardiomyopathy. Despite the fact that MRI can be performed safely in most patients with cardiac devices at 1.5T [1], many HF patients who would derive benefit from MRI do not undergo MRI largely due to image artifacts arising from implantable cardioverter-defibrillator (ICD). Specifically, an ICD located 5-10 cm away from the heart can induce a center frequency shift as large as 2-6 kHz [2], which renders standard radio-frequency (RF) pulse modules for T_1 weighting to be ineffective. Recently, the feasibility of wideband late gadolinium enhanced (LGE) was demonstrated for assessment of myocardial scarring in patients with ICD [2], where "wideband" refers to the inversion pulse. The purpose of this study was to develop and evaluate a wideband arrhythmia-insensitive-rapid (AIR) cardiac T_1 mapping pulse sequence [3] for assessment of myocardial T_1 in human subjects with ICD.

Methods: *(Pulse Sequence)* We developed a wideband AIR T_1 mapping pulse sequence by incorporating a saturation RF pulse with wide frequency bandwidth (8.9 kHz), in order to achieve uniform T_1 weighting in the heart with the presence of ICD. Specifically, we used B_1-insensitive train to obliterate signal (BISTRO)[4] as a train of 15 hyperbolic secant adiabatic inversion RF pulses (β=750 radians/s; μ=10; individual RF duration=3.07 ms; total duration = 106 ms) with crusher gradients in between RF pulses to minimize stimulated echoes. We note that in the context of magnetization saturation, T_2 relaxation during the RF time (46 ms out of 106 ms) of BISTRO is a benefit since the objective is to set the magnetization to zero. *(Human Experiment)* We tested the performance of original (saturation pulse frequency bandwidth=2.5 kHz) and "wideband" AIR cardiac T_1 mapping pulse sequences in 11 human volunteers at 1.5T (Siemens Espree) with and without ICD. To mimic a realistic situation [2], we taped an ICD on each subject's left shoulder approximately 5-10 cm superior to the left nipple, and performed original and wideband AIR cardiac T_1 mapping in short- and long-axis planes without administration of contrast agent. We used original AIR without ICD as the control to compare the results produced by wideband AIR. Original and wideband AIR T_1 mapping acquisitions used ultra-fast gradient echo read-out and the following relevant imaging parameters: FOV = 360 x 270 mm^2, slice thickness = 8 mm, acquisition matrix = 128 x 96 (PE), TE = 1.1 ms, TR = 2.2 ms, receiver bandwidth = 1000 Hz/pixel, center-out k-space ordering, readout duration = 132 ms, saturation-recovery time delay (TD) = 600 ms, flip angle = 10˚, breath-hold duration = 2-3 heart beats, acceleration factor (GRAPPA) = 1.6. *(Image Analysis)* AIR cardiac T_1 maps were generated using the Bloch equation describing T_1 relaxation in saturation recovery [3]. Left ventricular cavity and wall contours were drawn carefully to avoid partial volume averaging effects. For statistical analysis, for each measurement type (native blood and myocardial T_1) per cardiac plane, a single-factor analysis of variance was used to compare the mean T_1 values between four groups (original AIR without ICD (control), original AIR with ICD, wideband AIR without ICD, and wideband AIR with ICD), and Bonferroni correction was used to compare the mean values between the control and other three groups.

Results: Figure 1 shows representative native T_1 maps in short-axis and long-axis planes of the heart. Compared with original AIR without ICD as the control, original AIR with ICD produced less accurate T_1 results, whereas wideband AIR with and without ICD produced more accurate T_1 results. Averaging the results over 11 human subjects, the mean myocardial and blood T_1 measurements were significantly different between the four groups (Table 1; $p < 0.001$). Compared with original AIR without ICD as the control, only original AIR with ICD was significantly different in both imaging planes ($p < 0.05$). We note that native T_1 measurements (myocardial T_1 ~ 1100 ms; blood T_1 ~ 1500 ms) made with original AIR without ICD and wideband AIR with and without ICD are comparable to ex-vivo [5] and in vivo [6] myocardial and blood T_1 measurements reported in literature. We note that intra-cardiac leads do not generate significant artifacts (phantom data not shown due to space constraint).

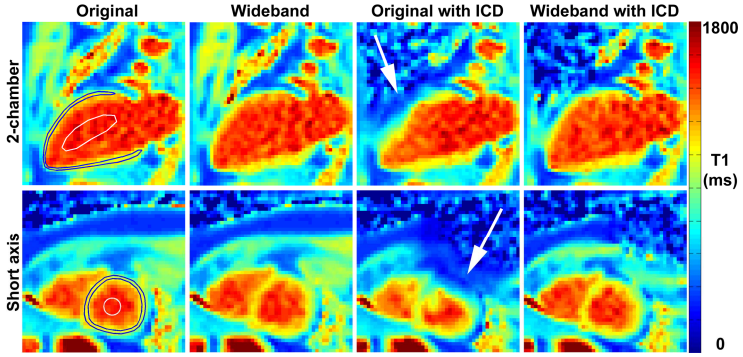

Figure 1. Representative original and wideband T_1 maps with and without ICD as shown. White arrows point to image artifacts caused by ICD.

Table 1. Mean myocardial and blood T_1 measurements over 11 human subjects. Percent error (relative to control) is reported in parenthesis. *$p < 0.05$ with respect to original AIR without ICD as the control.

Tissue Type	Original (ms)	Wideband (ms)	Original with ICD (ms)	Wideband with ICD (ms)
2-CH, Myocardium	1093.6 ± 42.1	1158.8 ± 44.5 (6.0%)	884.8 ± 84.8 (-19.1%)*	1114.9 ± 68.8 (2.0%)
SAX, Myocardium	1069.8 ± 29.3	1137.7 ± 28.6 (6.4%)	837.9 ± 115.8 (-21.7%)*	1091.4 ± 82.7 (2.0%)
2-CH, Blood	1470.0 ± 75.3	1498.3 ± 57.6 (1.9%)	1321.6 ± 124.7 (-10.1%)*	1489.7 ± 60.8 (1.3%)
SAX, Blood	1473.9 ± 89.2	1522.5 ± 52.3 (3.3%)	1241.0 ± 268.9 (-15.8%)*	1496.6 ± 58.3 (1.5%)

Conclusion: This study demonstrates the feasibility of wideband cardiac AIR T_1 mapping for imaging human subjects without significant image artifacts induced by ICD.

References: **[1]** Nazarian S, et al. Heart Rhythm. 2009;6(1):138-43. **[2]** Rashid S, et al. Radiology. 2014;270(1):269-74. **[3]** Fitts M, et al. Magn Reson Med. 2013;70(5):1274-82. **[4]** Luo Y, et al. Magn Reson Med. 2001;45(6):1095-102. **[5]** Stanisz GJ et al. Magn Reson Med. 2005;54(3):507-12. **[6]** Chow K et al. , Magn Reson Med. 2014;71(6):2082-95. **Funding:** NIH (HL116895-01A1), American Heart Association (14GRNT18350028).