Fat-water separated myocardial T_1 imaging of the right ventricle with IDEAL-T_1 saturation recovery gradient echo imaging

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Purpose: Myocardial T_1 mapping is emerging as powerful tool for tissue characterization; however analysis of the right ventricle (RV) remains a significant challenge due to the presence of epicardial fat and poor blood-tissue contrast that obfuscate measurements. We propose and evaluate a new fat-water separated saturation-recovery imaging sequence (IDEAL-T_1), with and without black blood preparation, for water-separated myocardial T_1 mapping, including the RV.

Methods: The IDEAL-T_1 approach combines a gated, segmented multi-echo gradient recalled echo readout for fat-water separation, based on the "iterative decomposition of water and fat with echo asymmetry and least squares estimation" (IDEAL) method[1], with saturation recovery T_1 mapping[2-4]. Two interleaved images, a non-saturation prepared image (I_{NS}) and a saturation prepared image (I_S), are acquired during diastasis for calculation of T_1. ***Typical IDEAL-T_1 Parameters:*** Sonata 1.5T, Siemens Healthcare, Erlangen, Germany. TE 2.06, 4.43, 6.8 ms, TR 8.85 ms, sine based flip angle ramp, initial flip angle 7° to target of 30° over 27 pulses, TS 600 ms, 8 mm slice thickness, FOV 360 x 259 mm, acquisition matrix 256 x 128, phase resolution 70%, 6/8 partial Fourier, 27 views per segments (4 shots per image), bandwidth 977 Hz/pixel, >4s recovery prior to I_{NS}. IDEAL-T_1 was run with a dark blood preparation, using a train of saturation pulses placed over the atria, parallel to the imaging slice, to saturate inflowing blood (IDEAL-T_1 DB), and with bright blood contrast (IDEAL-T_1) by omitting the inflow saturation. ***Simulations:*** Bloch equation simulations were performed to evaluate the accuracy of the sequence over a range of physiologic and imaging parameters (T_1, T_2, off-resonance, B_1, saturation efficiency). ***Phantoms:*** IDEAL-T_1 (with and without DB) was validated against an inversion-recovery spin-echo sequence in 14 phantoms with a physiologic range of T_1 and T_2 values (T_1 = 280-1425 ms). ***In-Vivo:*** Myocardial T_1 mapping was performed in the right and left ventricle (LV) of 8 healthy individuals (single basal short axis slice, end-expiration breath-hold) with IDEAL-T_1 DB and IDEAL-T_1, with comparison of both methods to a validated single-shot saturation recovery sequence (SASHA)[2]. IDEAL-T_1, (with and without DB) experiments were repeated three times for test/re-test and to evaluate the impact of signal averaging. ***Processing:*** For simulation, phantom and in-vivo studies, data from water-separated images were scaled by I_{NS} and fit to a 1-parameter mono-exponential curve, using a Bloch equations simulation look-up table approach to correct for residual incomplete recovery between I_S and I_{NS}. Repeated image acquisitions were registered, along with DB and non-DB sets, and pixel maps were generated of the individual acquisitions along with an average of the three. RV regions of interest were traced on the raw images in the inferior RV wall, while a septal region of interest was traced for the LV (**Fig. 1**).

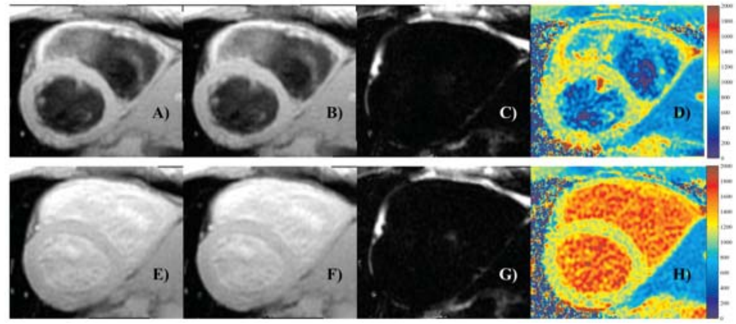

Figure 1. IDEAL-T_1images, with black blood prepared images in the top row, and bright blood prepared images below. A) & E) fat and water combined, B) & F) water separated images, C) & G) Fat separated images, and D) & H) T_1 pixel maps from water separated images. Note the difficulty in visualizing the right ventricle in the bright blood images, including the pixel map.

Results: Simulations revealed negligible T_1 dependence on T_1, T_2, and off-resonance (up to 250 Hz), but dependence on errors in B_1 and saturation efficiency. IDEAL-T_1 and IDEAL-T_1 DB phantom experiments show excellent agreement with spin-echo values with a mean overestimation of 3.5 and 4.7 ms, respectively. In vivo studies in 8 subjects (34±9 yrs, 8 males, 78.1±8.6 kg) showed mean differences of -18 and 32 ms for IDEAL-T_1 DB and IDEAL-T_1, respectively, compared to SASHA (Table 1). Visualization of the RV for analysis was only reliably achieved using IDEAL-T_1 DB, due to its superior blood-tissue contrast, and was possible in all subjects.

		Left Ventricle (LV)									Right Ventricle (RV)							
		SASHA	IDEAL-T_1 DB				IDEAL-T_1				IDEAL-T_1 DB				IDEAL-T_1			
			Avg	1	2	3	Avg	1	2	3	Avg	1	2	3	Avg	1	2	3
Fat & Water Image	T_1 (ms)	1152	1132	1132	1122	1121	1183	1184	1169	1184	1120	1120	1126	1109	1192	1192	1183	1192
	SD (ms)	14	45	45	32	28	32	35	42	55	48	48	55	54	38	35	57	43
	CV	-		-	1.2%	-		-	1.1%	-		-	1.4%	-		-	1.5%	-
Water Only	T_1 (ms)	-	1135	1135	1121	1127	1185	1185	1169	1184	1117	1117	1123	1112	1186	1186	1178	1186
	SD (ms)	-	49	49	30	33	32	36	42	53	45	45	52	51	37	34	58	43
	CV	-		-	1.1%	-		-	1.1%	-		-	1.5%	-		-	1.5%	-

Table 1. In vivo T_1 mapping data; Avg = signal averaged image, prior to pixel map calculation, SD=standard deviation, CV=coefficient of variation

Discussion: IDEAL-T_1 myocardial T_1 values are similar to a clinical reference standard. IDEAL-T_1 DB enables visualization and measurement of RV T_1 values, but systematic T_1 underestimation may be due to perfusion related effects from the dark blood saturation preparation.[4]

Conclusion: IDEAL-T_1 provides the benefit of fat-water separation with quantitative myocardial T_1 mapping, and when combined with a dark blood preparation, allows for T_1 mapping in the right ventricle. Further work needs to be done to address potential perfusion related effects from the black blood preparation, as well as further evaluation in a larger sample to obtain normative data.

References: 1.Reeder–JMRI 2007; 2.Chow–MRM 2013; 3.Higgins–Med Phys 2005; 4.Wacker–MRM 1999