Right ventricular myocardial T1 and extracellular volume fraction (ECV) measurements using high resolution ANGIE T1 mapping

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Target audience: Clinicians and scientists working on cardiac T1 mapping.

Introduction: T1 mapping has become an important method for the quantitative assessment of left ventricular (LV) myocardial fibrosis. T1 mapping of thin structures such as the right ventricular (RV) and left atrial walls would also be valuable in disorders such as arrhythmogenic right ventricular cardiomyopathy, pulmonary hypertension, congenital heart disease, and atrial fibrillation. However, MOLLI[1], the most widely used T1 mapping technique, has limited spatial resolution because data are acquired within a breathhold. We developed an Accelerated and Navigator-Gated look-locker Imaging sequence for cardiac T1 Estimation (ANGIE)[2,3], which enables high-resolution T1 mapping by removing the breathhold constraint. We investigated T1 mapping of the RV wall in healthy volunteers and heart failure patients using ANGIE.

Methods: ANGIE uses readout segmentation and navigator-gating to remove the breathhold constraint and achieve high spatial resolution. For acceleration, we used compressed sensing (CS) with matrix rank sparsity[4] in conjunction with parallel imaging. Furthermore, to reduce the total scan time we developed an adaptive data acquisition algorithm[3], which responds to navigator rejection of data by recalculating, in real-time, a k-t sampling pattern that is well-suited for CS reconstruction and T1 estimation. High-resolution ANGIE (1.2-1.3x1.2-1.3 mm^2) was compared with standard-resolution MOLLI (2.0-2.3x2.5-2.9 mm^2) for RV T1 mapping in nine healthy volunteers (age 28±5 yrs). Also, since estimation of myocardial extracellular volume fraction (ECV) requires the use of a contrast agent, ANGIE estimates of RV ECV were evaluated in five heart failure patients referred for implantable cardioverter defibrillators. All imaging was performed on a 1.5T system (Avanto, Siemens) in accordance with protocols approved by our institutional review board. A single short-axis slice was imaged in each subject. In patients, the MRI protocol included: 1) pre-contrast ANGIE, 2) late gadolinium enhancement (LGE) acquisitions after Gadolinium-DTPA (Gd-DTPA) injection (0.15mmol/kg), and 3) multiple post-contrast ANGIE acquisitions at intervals of 5 mins up to 30 mins post-contrast. A slice thickness of 4 mm was used to reduce through-plane partial volume effects. The acquisition was performed at end systole to take advantage of the thicker RV wall and greater separation of the RV wall from the liver and the chest wall. Manual contours were drawn in a conservative manner to exclude trabeculations using magnitude images. ECV was estimated using the hematocrit and the slope of R1 of myocardium versus R1 of LV blood pool[5].

Results: As shown in Figure 1, high-resolution ANGIE T1 mapping clearly resolves the RV wall (Fig. 1A, arrows), whereas MOLLI demonstrates substantial partial volume effects in the RV wall (Fig. 1B, arrows). Table 1 summarizes the scan time and myocardial T1 estimates from healthy volunteers. For ANGIE, the RV T1 (980±96 ms) was in close agreement with the LV T1 (942±90 ms), while for MOLLI, the RV T1 (1076±157 ms) trended higher (p=0.097) compared to the LV T1 estimate (974±58 ms). The intrascan variation in the RV T1 estimate was greater for MOLLI than for ANGIE (p<0.05). The higher variation using the lower-resolution MOLLI method was likely due to partial volume effects where blood was included in RV voxels. Figure 2 shows example results from a patient. The estimated ECV value for the RV was 28.0±1.6% and for non-infarcted LV myocardium (determined by absence of LGE) was 27.0±2.4%, which fall within the range of published values for normal volunteers and remote myocardium in patients with ischemic heart disease[6,7].

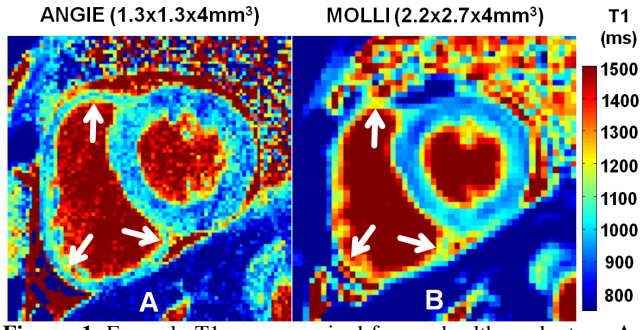

Figure. 1. Example T1 maps acquired from a healthy volunteer. **A**: High-resolution ANGIE (1.3x1.3x4 mm^3), and **B**: lower-resolution MOLLI (2.2x2.7x4 mm^3). The T1 maps illustrate that ANGIE can resolve the thin right-ventricular wall *(arrows)*, while MOLLI has errors due to partial volume effects.

Conclusions: ANGIE provides high-resolution T1 mapping, which is critical for the assessment of thin structures such as the RV wall, within a clinically-acceptable scan time. To the best of our knowledge, this is the first report of RV T1 and ECV estimates. ANGIE opens the prospect of quantitative assessment of thin cardiovascular structures such as the RV and left-atrial walls and subtle features of the peri-infarct zone.

References: (1) Messroghli et al: MRM 2004. (2) Mehta et al: JCMR 2012. (3) Mehta et al: Proc. of ISMRM 2013. (4) Lingala et al: IEEE TMI 2011. (5) Salerno M. et al JMRI 2013. (6) Kellman P. et al JCMR 2012. (7) Ugander M. et al EHJ 2012.

Table. 1. Scan time and myocardial T1 estimates from healthy volunteers. (* p<0.05 for std. dev. of RV T1 using ANGIE vs. std. dev. of RV T1 using MOLLI)

	MOLLI	ANGIE
Scan Time	17 (hb)	157±53 s
LV Myocardial T1 (ms)	974±58	942±90
RV Myocardial T1 (ms)	1076±157	980±96*
Accel. Rate	1.7 (Parallel)	2.0 ± 0.1 (CS)
Navigator Efficiency (%)	-	59 ± 18

Table. 2. ECV results from heart failure patients enrolled in our study and from published values from the literature.

	ECV (%)
RV myocardium	28.0±1.6
Remote LV myocardium	27.0±2.4
LV myocardium in healthy volunteers (literature value[6])	25.4±2.5
Remote LV myocardium in ischemic patients (literature value[7])	27.0±3.0

Acknowledgements: This work was funded in part by NIH R01 EB001763, NHLBI K23 HL094761, American Heart Association Grant-in-Aid 12GRNT12050301 and Siemens Medical Solutions.

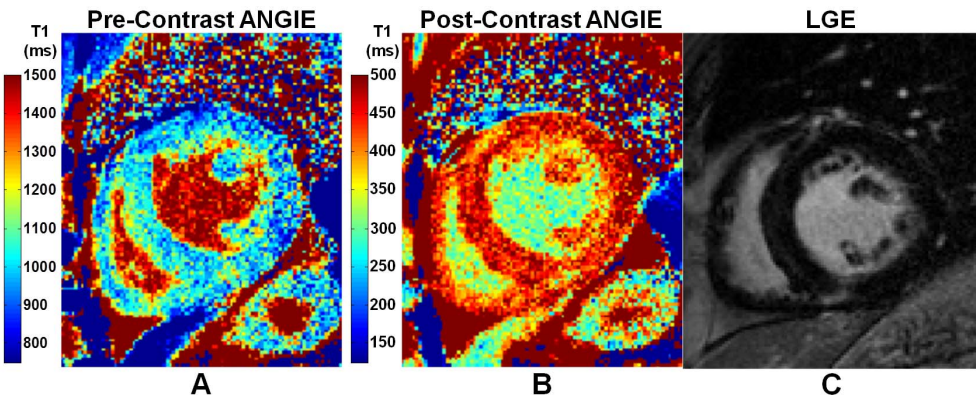

Figure. 2. Example results acquired from a heart failure patient. **A:** ANGIE T1 map prior to injection of Gd-DTPA. **B:** ANGIE T1 map 25 minutes after injection of Gd-DTPA. **C:** Late gadolinium enhancement (LGE) image. Both pre- and post-contrast ANGIE T1 maps show good definition of the RV.