COMBINED SATURATION/INVERSION RECOVERY SEQUENCES FOR IMPROVED EVALUATION OF SCAR AND DIFFUSE FIBROSIS IN PATIENTS WITH ARRHYTHMIA OR HEART RATE VARIABILITY

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INTRODUCTION: Cardiac arrhythmia and heart rate variations are common among patients with cardiac disease and adversely impact the image quality of various cardiac MR images. In late gadolinium enhancement (LGE), the clinical gold standard for assessment of scar/fibrosis (1), the heart rate variability and arrhythmia imposes an additional weighting in k-space which usually manifests as ghosting artifacts and signal inhomogeneity in the myocardium and blood. In the Modified Look-Locker imaging (MOLLI) sequence (3), the most widely used T1 mapping sequence for assessment of diffuse, interstitial fibrosis, the signal disturbance induced by multiple imaging pulses after a single magnetization preparation varies based on the length of the RR-interval. This induces a heart rate dependency, especially for tissues with long T_1 values. In this study, we sought to develop an improved magnetization preparation to eliminate the sensitivity of inversion recovery based sequences for assessment of scar or diffused fibrosis to cardiac arrhythmia and heart rate variability.

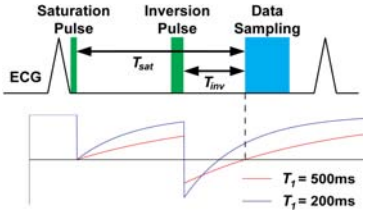

Fig. 1: *Magnetization preparation employed in the SAPPHIRE sequence.*

METHODS: ***Sequence:*** Figure 1 shows the schematic of the proposed sequence. A non-selective saturation pulse is added right after the detection of each R-wave. This dephases the magnetization in the imaging volume and erases the magnetization history. It is then followed by an inversion pulse to enhance T_1-weighted contrast in the images. We refer to this magnetization preparation scheme as SAturation Pulse Prepared Heart-rate-independent Inversion REcovery (SAPPHIRE). We propose a SAPPHIRE LGE sequence, where the dependence on the preceding RR-intervals is removed by the magnetization preparation. This eliminates insufficient recovery as a source of ghosting artifacts, while the strong contrast of infarcted tissue against a dark myocardial background is preserved with the appropriate choice of T_{inv}, allowing visualization similar to conventional LGE imaging. In myocardial T_1 mapping, SAPPHIRE erases the magnetization history, which eliminates the need for rest-periods, and enables efficient imaging that allows for heart rate independent estimation of T_1 values. In this sequence, nine ECG-triggered SAPPHIRE images are acquired as single-shot acquisitions in one breath hold per slice. Since T_{inv} of the different images can be chosen independently, a denser sampling of the early part of the T_1 relaxation curve, which is most sensitive to T_1 values, is possible.

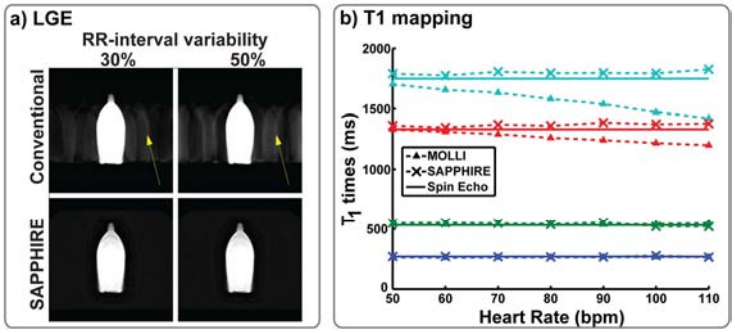

Fig. 2: a) *Images of a bottle-phantom during randomly simulated arrhythmia using conventional and SAPPHIRE LGE. b) shows T_1 values determined in phantom measurements using the studied sequences at various heart rates.*

Phantom Imaging: All imaging was performed on a 1.5T Philips Achieva system. For LGE imaging, the presence of arrhythmia-induced ghosting artifacts in conventional and SAPPHIRE LGE was studied in a phantom using a 3D GRE acquisition. An arrhythmic ECG was simulated using random RR-interval lengths with a mean heart rate of 90 bpm, and standard deviations equal to 30% and 50% of the mean length. SAPPHIRE T_1 mapping and MOLLI (2) were evaluated in a T_1-phantom (4) using an inversion recovery spin-echo sequence as reference. Imaging was repeated at several simulated heart rates in sinus rhythm to test for systematic errors.

In-Vivo Imaging: 3D LGE images were acquired in 2 arrhythmic patients, 15-25 minutes after injection of 0.1 mmol/kg of Gd-BOPTA, using both the conventional and SAPPHIRE LGE sequences. In-vivo 2D multi-slice T_1 mapping was performed in five healthy subjects and two patient using MOLLI and SAPPHIRE T_1 mapping 5-30 minutes after injection of Gd-BOPTA. Images were quantitatively evaluated in terms of T_1 times in the blood and myocardium.

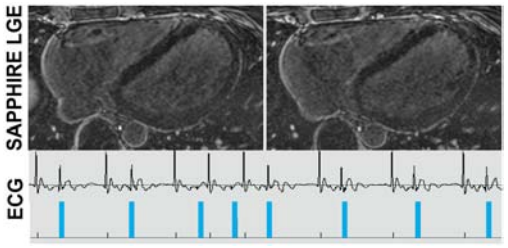

Fig. 3: *SAPPHIRE LGE images acquired in a patient with arrhythmic ECG.*

RESULTS: ***Phantom Imaging:*** Fig. 2a shows phantom measurements, indicating that SAPPHIRE LGE successfully removes arrhythmia-induced ghosting artifacts, which are readily visible in conventional LGE even for 30% RR-interval variation. However, the contrast-to-noise ratio is decreased by 22-39% using SAPPHIRE LGE compared to conventional LGE in these measurements. Fig. 2b depicts T_1 quantification results of the phantom for various T_1 values and heart rates. SAPPHIRE T_1 mapping is in good agreement with MOLLI and the reference measurement for short T_1 times. For long T_1 times SAPPHIRE T_1 mapping shows a slight overestimation (relative-difference<4.4%), while MOLLI markedly underestimates compared to the spin-echo sequence. Significant correlation between MOLLI T_1 times and the heart rate are shown in compartments with T_1>600 ms (R^2> 0.98). No correlation is observed between the heart rate and SAPPHIRE T_1 times in this range (R^2<0.49).

In-Vivo Imaging: Fig. 3 shows artifact-free SAPPHIRE LGE images acquired in a patient with frequent premature atrial beats. In-vivo T_1 maps are depicted in Fig. 4, where the proposed sequence results in more homogenous T_1 maps. SAPPHIRE T_1 mapping and MOLLI show no significant difference (P > 0.37) in quantifying T_1 values in the myocardium, the left or right ventricles. However, the SAPPHIRE-based sequence provides high quality T_1 maps, despite markedly shorter breath hold durations (7-10s vs. 13-19s).

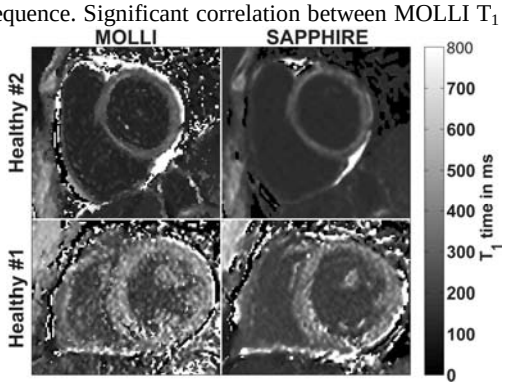

Fig. 4: *T_1 maps acquired after injection of a contrast agent using MOLLI and SAPPHIRE T_1 mapping.*

CONCLUSIONS: We have introduced a novel magnetization preparation scheme, combining saturation and inversion pulses, for LGE and T_1 mapping sequences, allowing improved assessment of scar and fibrosis in cardiac MRI. Phantom and in-vivo results demonstrate the robustness of SAPPHIRE LGE imaging to ghosting artifacts induced by arrhythmia and heart rate variability, allowing artifact-free scar imaging for arrhythmic patients. In T_1 mapping, this preparation allows for a shorter sequence with more homogenous T_1 maps, while enabling heart rate invariant estimation of T_1 values, which is essential for characterizing fibrotic tissue.

REFERENCES: 1. Kim, R.J. NEJM, 2000; 2. Vallée, J.-P. ACAD.RAD., 1999; 3. Messrohgli, D.R. MRM, 2004; 4. de Bazelaire, C.M.J. Radiology, 2004