Improved Excitation Fidelity in Cardiac Imaging with 2-Spoke Parallel Excitation at 7 Tesla

Sebastian Schmitter[1], Lance DelaBarre[1], Xiaoping Wu[1], Andreas Greiser[2], Dingxin Wang[3], Kamil Ugurbil[1], and Pierre-Francois Van de Moortele[1]

[1]*Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States,* [2]*Siemens Healthcare Sector, Erlangen, Bavaria, Germany,* [3]*Siemens Medical Solutions USA, Inc., Center for Magnetic Resonance Research, University of Minnesota, Minneapolis, MN, United States*

INTRODUCTION. Cardiac MRI has become an increasingly important tool for cardiovascular investigations. However, the heart is also a very challenging organ for MRI due to cardiac and respiratory motion. On the other hand, cardiac MRI may greatly benefit from ultra high field (UHF) providing higher SNR and increased intrinsic contrast than lower field [1]. However, the shorter RF wavelength imposes additional problems resulting in transmit B1 (B1+) inhomogeneities and thus contrast variations through the heart. These variations have been successfully addressed at 7T using a multi-channel transmit (TX) coil in combination with B1 shimming (with fixed RF amplitude/phase for each TX channel) [1], but further improvements are expected by using parallel transmission (pTX) with multi-spoke RF pulses (with different sets of RF amplitudes/phases for each spoke) as demonstrated in the brain and in the liver at 7T [2,3]. However, additional challenges are involved for applying multi-spoke pTX RF pulses spokes to cardiac MRI at 7T, including pTX sequence synchronization with ECG trigger, rapid and robust multi-channel ECG triggered B1+ calibration, and sensitivity to motion. In this initial work we investigate the impact of 2-spoke RF pulse design on cardiac imaging at 7T using a 16-channel pTX system.

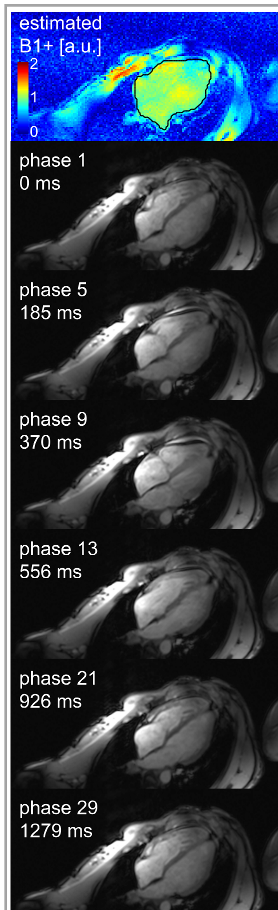

Fig.2: *bottom:* 4 chamber view of different cardiac phases, acquired in CINE mode with 2 spokes. *Top*: Corresponding B1+ estimation map (scale different to Fig 1 to appreciate overall pattern)

METHODS. Healthy volunteers were imaged after signing IRB-approved consent on a human 7T magnet (Siemens, Erlangen) equipped with a 16 channel pTX system using a 16 channel transceiver body coil [4]. We used modified MR sequences enabling cardiac triggered acquisitions preserving full-pTX capability. B1+ sensitivity maps of each transmit (TX) channel were obtained sequentially using a fast, small flip angle estimation technique [5] with single slice gradient echo (GRE) acquisitions. Each map was acquired within 484ms during diastole (300ms delay to trigger). 1-spoke and 2-spoke pTX RF pulses were designed based on magnitude least squares (MLS) optimization [6] aiming at homogeneous excitation in manually drawn ROI. 3 different excitations were compared: a) standard RF pulse (1-spoke) with non-optimized RF phases and equal RF amplitude through all channels, b) same as a) (1-spoke) but with optimized RF magnitude/phase and c) 2-spoke RF pulse with magnitude/phase optimized for each spoke and channel. RF pulse duration of each spoke was set to 800 us in 2-spoke pulses and to 1600us in case of 1-spoke pulses, so that total RF pulse duration (w/o gradient ramps) was always the same. A Hanning filtered SINC shape (BWTP=4) was used for all sub-pulses. Coefficient of variation (CV, i.e. std/mean) in target ROI, total RF energy and peak energy per channel were computed for all RF pulses, designed with a same excitation flip angle target. For technical reasons, cardiac triggered ΔB_0 maps could not yet be collected in pTX mode. Acquisitions were performed in axial- and 4-chamber views using a GRE sequence in CINE mode with the following parameters: 384x228 matrix, resolution 1.2x1.2x5 mm^3; 1 spoke TR/TE = 41.7/2.5ms, 32 phases; 2 spoke: TR/TE = 44.8/2.7ms, 29 phases.

RESULTS. Fig.1 shows axial views of predicted B1+ maps (top) and GRE cardiac images (bottom) using 1- and 2-spokes RF pulses. Although absolute flip angle maps could not be measured with our pTX sequences, signal patterns are highly consistent with predictions based on measured B1+ maps, including in more posterior regions (e.g. see aorta, see also Fig.2). Note, that each B1+ map was acquired within just ~500ms, which confirms the robustness of our fast B1+ estimation approach [5]. Homogeneity improved with 2-spoke excitation, with CV dropping from 16.4% to 10.0% with only a slight increase in RF energy, from 100% up to 112%. Note that applying a 2-spoke excitation with same RF energy (100%) would only marginally increase CV from 10.0% to 10.4% - see Tab.1. When compared with a non-optimized (initial) set of RF phases, both 1- and 2-spoke excitation largely improved excitation fidelity. Fidelity improvement with 2-spoke over 1-spoke pulses especially occured near the edges of the ROI (especially posteriorly), as demonstrated in Fig.1. Fairly different relative RF energy distributions are generated through the 16 channels resulting in ~40% higher max. energy per channel for the axial 1- compared to 2-spoke. Due to conservative RF safety setting (limiting max RF energy per channel), the axial 1 spoke RF pulse amplitude was reduced by a factor 0.9 leading to slightly lower B1+/flip angle. Fig. 2 shows GRE images obtained with 2-spoke excitation in 4-chamber view at different cycle phases. Here, even with a 2-spoke pulse, higher residual inhomogeneity was observed with CV=12.3%, and higher RF energy was needed (170%) when compared to axial views (Tab.1). These higher values are likely the result of a fairly larger ROI size, while the orientation may also play a role. Note the absence of significant excitation pattern change through the cardiac cycle.

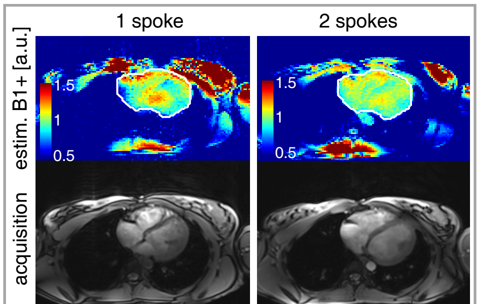

Fig.1: estimated B1+ maps for 1 and 2 spoke excitation (top) and last cardiac phase of corresponding CINE acquisition (bottom)

Tab.1: summarized quantified results of exictation fidelity, RF energy and max. of energy per channel. Gray shaded columns correspond to Fig.1 and Fig.2.

	axial view				4 chamber view	
	init. phase	1 spoke	2 spoke	2 spoke	1 spoke	2 spoke
CV	47.4%	16.4%	10.0%	10.4%	15.2%	12.3%
Energy	228%	100%	112%	100%	170%	170%
max(Energy per Channel)	48%	100%	60%	55%	129%	102%

DISCUSSION. In this work 2-spoke pTX excitation RF pulses were applied to cardiac imaging at 7T. Satisfactory cardiac triggered B1+ maps were rapidly estimated in one cardiac phase per channel. As was shown in other organs, 2-spoke excitation significantly improves excitation fidelity while reducing RF energy compared to 1-spoke. Absolute flip angle maps are desirable for validation but too difficult to obtain in the heart with our existing pTX methods. Even though no B0 maps could be included for RF design in the present work, very good agreement between final images (non RX profile corrected) and B1+ based predictions was consistently observed in both axial and 4-chamber views. In conclusion, pTX 2-spoke excitation in the heart is practically feasible, providing improved excitation fidelity and reduced peak RF amplitude as well as reduced total RF energy.

ACKNOWLEDGMENTS: P41 EB015894, S10 RR026783, R21-EB009138, KECK Foundation. **REFERENCES** [1] Suttie et al. NMR Biomed 2011, 25:27 [2] Setsompop et al. MRM 2008, 60:1422 [3] Wu et al. ISMRM 2012, 2940 [4] Snyder et al., MRM 2009, 61:517 [5] Van de Moortele et al. ISMRM 2009, 367 [6] Setsompop et al. MRM 2008, 59:908