Balanced Left Ventricular Myocardial SSFP-Tagging at 1.5 and 3 Tesla

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Introduction: SSFP-Tagging (SPAMM tagging and balanced CINE SSFP imaging) offers a substantial improvement in tag-tissue contrast, tag-persistence and overall *SNR* when compared to conventional rf-spoiled gradient echo tagging methods [1-3]. MR imaging at 3T is ideally suited for the application of SSFP-Tagging since it offers prolonged T_1-relaxation times in myocardial tissue (867ms at 1.5T versus 1115ms at 3T [4]) and thus reduced tag fading. Moreover, previous studies at 1.5T have shown that small flip angles of 20-30° provide an ideal tag-tissue contrast [1, 2]. Therefore, SSFP-Tagging at 3T has the potential to improve myocardial *SNR* and thus tag-tissue contrast at these flip angles without specific absorption rate (SAR) limitations.
The aim of this study was to directly compare the performance of SSFP-Tagging at 1.5T and 3T in a study with 16 normal volunteers. Specifically, optimal imaging parameters were evaluated based on a quantitative analysis of tag-tissue contrast, tag-fading times, tag-persistence, and a tag quality index (combination of myocardial SNR and tag persistence). To account for SSFP specific artifacts the quantitative image analysis was amended by a blinded grading of image quality by two observers.

Methods: Left ventricular myocardial tagging in basal, mid-ventricular and apical short-axis locations was evaluated in 16 normal volunteers (age = 23.1±1.2 years). All measurements were performed on 1.5T and 3T systems (Sonata & Trio, Siemens, Germany) with identical SSFP-Tagging parameters: TE = 1.53 ms, TR = 3.06 ms, FOV = (380 x 330) mm^2, spatial resolution = 1.5 x 1.8 mm^2, slice = 8mm, temporal resolution = 36.7ms, scan time = 15 heart beats. Grid tagging preparation (spacing = 8mm) was embedded in a steady state storage scheme [5]. Tag persistence and SNR were analyzed by varying flip angles from 10° to the SAR limit.
Quantitative analysis of *SNR* in basal, mid-ventricular and apical locations for all flip angles, field strengths, and CINE time-frames was performed. Regions of interest (ROIs) were manually drawn to determine the signal intensity for tagged (S_{Tag}) and non-tagged myocardium (S_{Myo}). Tag contrast $\Delta SNR(t) = (S_{Myo}(t) - S_{Tag}(t))/noise$ was calculated as the difference of tagged and non-tagged myocardial *SNR*. A characteristic tag fading time T_f and an initial tag contrast ΔSNR_0 was calculated by fitting the measured tag-tissue contrast to an exponential decay $\Delta SNR(t) = \Delta SNR_0 \exp(-t/T_f)$.
Tag persistence = $T_f \cdot \ln[\Delta SNR_0/SNR_{thresh}]$ was defined as the time when $\Delta SNR(t)$ reached a detectability threshold $SNR_{thresh} = 6$ at which tagged and non-tagged regions could no longer be discriminated visually. A *Tag Quality Index* = *Tag Persistence* x mean(SNR_{Myo}) was defined based on the assumption, that high myocardial SNR in combination with long tag persistence is desirable for SSFP-Tagging.

Results: The maximum flip angle for SSFP-Tagging below SAR limits at 3T was 37.0° +/- 2.8° and 66.1° +/- 12.4° for 1.5T. For all 16 volunteers ROI analysis was performed in 498 CINE data sets (3 slice locations, all flip angles, both field strengths) in a total of 10753 images (including all time frames). In each image, 6 ROIs (2 x non-tagged tissue, 2 x tagged tissue, blood pool, and background noise) were drawn.
Figures 1 and 2 illustrate that non-tagged mean myocardial *SNR* was considerably improved at 3T for all flip angles. For both field strengths, higher flip angles result in opposing effects: beneficial systolic ΔSNR increase but unfavorable tag-fading time increase. Note that although both 1.5T and 3T demonstrated only small changes in tag fading times, the much improved mean myocardial SNR resulted in considerably improved tag persistence and tag quality index at 3T for all short axis locations (figure 3). Both tag persistence and the tag quality index demonstrated optimal SSFP-Tagging performance for a flip angle of 20°. Diastolic tag visibility was clearly improved at 3T and resulted in enhanced maximal average tag persistence at 20° of 789ms +/- 128ms compared to 523ms +/- 40ms at 1.5T.
Image quality grading by two independent observers revealed no significant differences were between 1.5T and 3T indicating that SSFP-Tagging could reliably be performed at 3T without loss of image quality or increased artifact level.

Discussion: SSFP-Tagging at 3T has proven to be superior to 1.5T and provides significantly enhanced tag persistence and myocardial SNR while maintaining overall image quality and artifact level. Average tag persistence at 3T was improved by 50% to almost 800ms resulting in visible tag-tissue contrast during diastole and even throughout the entire cardiac cycle for heart rates > 75 beats per minute. Compared to data acquisition at 1.5T, the flip angle selection for SSFP-Tagging at 3T was limited by SAR. However, the optimal trade-off between tag persistence and myocardial SNR was found at a rather low flip angle of 20° which was below SAR limits for all experiments. Consequently, drawbacks related to SAR which may affect other SSFP applications at 3T do not apply to SSFP-Tagging as performed in this study.

References: 1. Herzka DA, et al. Magn Reson Med 2003;49(2):329-340 **2.** Markl M, et al. Radiology 2004;230(3):852-861. **3.** Johnson TR, et al. Eur Radiol 2007;17(9): 2218-2224. **4.** Schar M, et al. Magn Reson Med 2004;51:799–806 **5.** Scheffler K, et al. Magn Reson Med 2001;45(6):1075-1080.

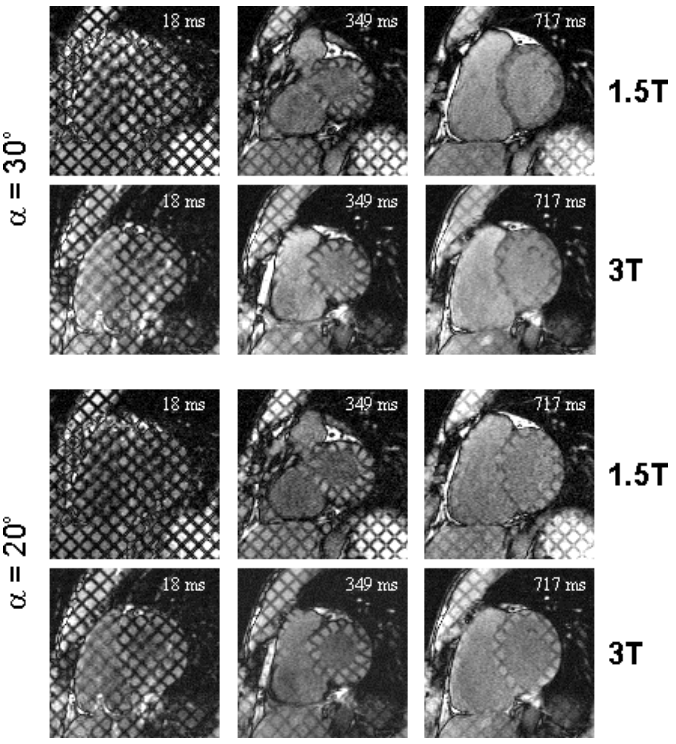

Fig. 1: SSFP-Tagging of a basal slice of a normal volunteer's heart at 1.5T and 3T for three different flip angles 20° and 30°. For each flip angle and field strengths 3 different time-frames representing different stages of left ventricular contraction and expansion are displayed. The improvement in SNR and resulting increase in tag-tissue contrast is clearly visible in all 3T images. In addition, 3T imaging demonstrated improved late diastolic tag visibility along the entire left ventricular wall for all flip angles.

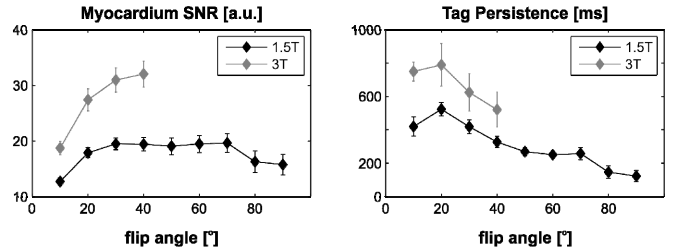

Fig. 2: Comparison of average signal, contrast, and tag dynamics as a function of the SSFP-Tagging flip angle for 1. All data points represent averages over 16 volunteers and three short axis slice locations (base, mid, apex). Left: Averaged SNR of non-tagged myocardial regions as a function of the imaging flip angle. Right: Tag persistence obtained by exponential curve fitting to tag-tissue contrast curves indicating optimal SSFP-Tagging performance at a flip angle of 20° for both 1.5T and 3T. Note that at 3T the maximum flip angle was limited to 40° due to SAR requirements.

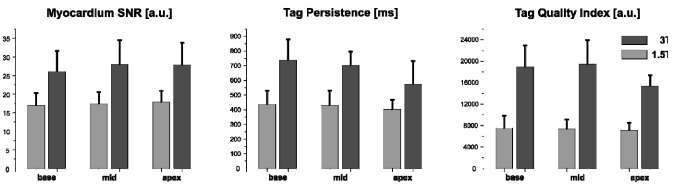

Fig. 3: Comparison of myocardial signal, tag persistence, and tag quality index for different short axis locations. All bars represent averages over 16 volunteers and flip angles ranging from 10-40°. Standard deviations indicate the variation between different flip angles. All differences between 1.5T and 3T were significant (unpaired, two-sided t-test, $p<0.05$).