Very High Temporal Resolution (<10 ms) Cine-EPI for Myocardial Tagging is Feasible and Has More Persistent Tag Lines than a Conventional Gradient Echo Sequence

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Introduction: Myocardial tagging is a powerful technique for assessment of regional cardiac function. It allows the clinician to qualitatively evaluate ventricular performance by visually assessing tag deformations, or quantify regional wall motion using one of a number of postprocessing algorithms. One of the key requirements of a robust tagging sequence is preservation of the tags throughout the cardiac cycle, which can be challenging due to T_1-relaxation. In addition, temporal resolution is extremely important because it is often crucial for the detection of subtle wall motion defects.

Echo Planar Imaging (EPI) belongs to the class of rapid imaging techniques that has shown utility in fast cardiac imaging, particularly in perfusion. Because of the increased rf-pulse spacing (compared to conventional, single-echo Gradient Echo (GRE)), cine-EPI should see decreased tag fading over the cardiac cycle. Additionally, extremely high temporal resolutions should be feasible. The purpose of this study was to demonstrate the feasibility of a very high (<10 ms) temporal resolution cine EPI tagging sequence, and to show that tag lines are better preserved throughout the cardiac cycle compared to a conventional tagged cine-GRE sequence.

Methods: To demonstrate theoretically that tags should be preserved longer using cine-EPI, we performed a simple simulation using the Bloch Equations to compare the signal trajectory of tagged (vs. untagged) myocardium for cine-GRE and cine-EPI at 1.5 T. We assumed the following: $T_{1,myocardium}/T_{2,myocardium}$ = 900 ms/40 ms; flip angle = 15°; GRE: TR/TE = 4 ms/2 ms; EPI: TR/TE = 9 ms/5 ms; R-R interval = 1000 ms; one R-R interval of "dummy pulses" to achieve steady-state prior to acquisition. We simulated myocardial signal for tagged myocardium (S_{tag}) and untagged myocardium (S_{myo}), and used the simulation results to calculate the ratio between S_{tag}/S_{myo} at 500 ms and the time ($t_{50\%}$) when S_{tag}/S_{myo} = 50% for both GRE and EPI.

Experimental studies were performed in volunteers (n=6; 1 male; mean age = 22 ± 2 years) on a 1.5 T MAGNETOM Avanto (Siemens Healthcare, Erlangen, Germany). A 32-channel phased array coil (Invivo, Gainesville, Florida) was used for signal reception. After localization of the short axis view two breath-hold scans were performed in a mid-ventricular slice; one with the cine-EPI tagging sequence (TR/TE = 9.1 ms/5.2 ms; echo train length = 4; temporal resolution = 9.1 ms), and one with the conventional cine-GRE tagging sequence (TR/TE = 3.7 ms/1.9 ms; temporal resolution = 14.7 ms). Parameters common to both sequences: FOV = 270 x 360 mm^2; matrix = 96 x 128; flip angle = 15°; 4 k-space lines acquired per phase per cardiac cycle; parallel acceleration x 2 using GRAPPA with external reference lines; total heartbeats per acquisition = 13. Tagging preparation consisted of a grid tag with 8 mm separation.

Two experienced cardiac MR readers independently evaluated the volunteer data sets. Each reviewer was asked to rate the image quality of each data set on a scale of 1-4, where 1 = poor image quality, non-diagnostic; 4 = excellent image quality. Image scores for each reviewer were compared using a Wilcoxon Matched-Pairs Signed-Rank Test with α=0.05. Additionally, for each sequence, each reviewer was asked to record the trigger time of the final image that still has tags which are conspicuous enough for qualitative image analysis. These values were compared using a matched-pairs t-test (α=0.05).

Results: Results from the simulation are shown in Figure 1. S_{tag}/S_{myo} at 500 ms for GRE and EPI was 0.94 and 0.72 respectively. $t_{50\%}$ for GRE and EPI was 232 and 342 ms respectively. The experimental studies were successful in all subjects. For image quality analysis, Reviewer #1 gave a mean score (± Standard Deviation) of 2.8 ± 0.4 and 3.3 ± 0.5 for GRE and EPI respectively. For the same measures, Reviewer #2 gave mean scores of 3.7 ± 0.5 and 3.2 ± 0.8. No statistically significant differences between the two techniques were detected for the scores given by either reviewer. For the tag duration evaluation, Reviewer #1 found mean tag duration of 408 ± 40 ms for GRE and 552 ± 82 ms for EPI. Reviewer #2 found mean tag duration of 456 ± 48 ms for GRE and 530 ± 64 ms for EPI. For both reviewers, the differences in tag duration for GRE and EPI were statistically significant (p<0.05).

Discussion and Conclusion: We have shown that extremely high temporal resolution (<10 ms) cine-EPI with tagging is feasible and, using simulations and volunteer data, that the tag lines persist longer than a conventional GRE sequence with the same imaging parameters. Additionally, image quality is comparable to cine-GRE. Tag lines using cine-EPI were sufficient for qualitative analysis for an average of 552 ms across the volunteers. Spatial resolution (2.8 x 2.8 mm^2) may need further improvement for accurate quantitative analysis, but this could be further improved by using a combination of higher parallel acceleration factors and field strength.

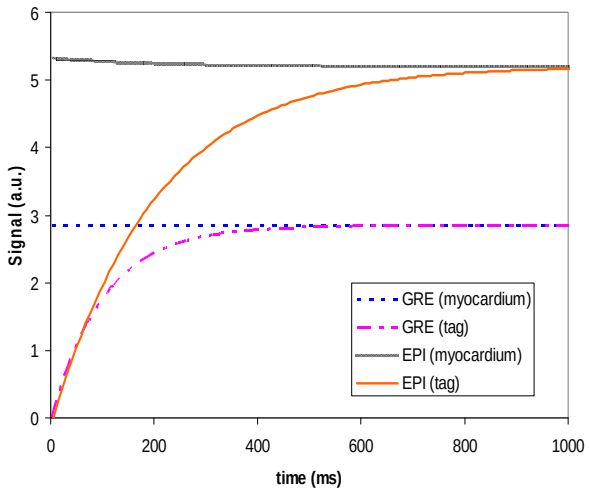

Figure 1: Simulation results for GRE and EPI for myocardium (tagged/untagged) over the cardiac cycle (R-R = 1000 ms). 1 dummy beat was applied, which is why the myocardial signal starts close to steady-state. Tagged signal recovers more slowly for the EPI simulation.

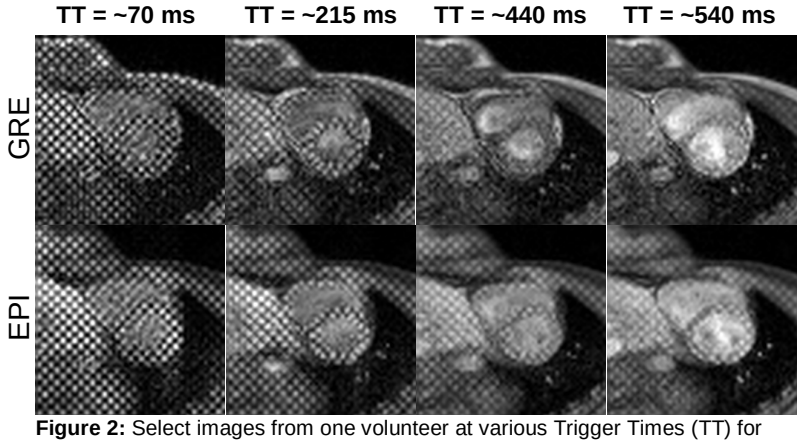

Figure 2: Select images from one volunteer at various Trigger Times (TT) for the tagged GRE-cine and EPI-cine. Tags were visible for both sequences through mid-systole (215 ms), but both reviewers agreed that for this volunteer, the tags were still diagnostically useable at TT=440 ms for EPI but not for GRE. Both reviewers agreed that neither sequence had diagnostically useable tags by TT=540 ms. Temporal resolution for GRE: 14.7 ms; EPI: 9.1 ms.