Accelerated true-FISP Multi-slice First Pass Perfusion Imaging using TSENSE

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INTRODUCTION

Parallel imaging is applied to first pass contrasted enhanced cardiac MR to yield greater spatial coverage for a fixed temporal resolution. The method combines true-FISP imaging with rate R=2 acceleration using TSENSE. Single heart beat temporal resolution was accomplished with spatial coverage of 6 slices at heart rates up to 80 bpm and 4 slices up to 120 bpm. Increased spatial coverage is demonstrated with consistently good contrast and overall image quality.

Coverage of the entire heart during a first pass contrast enhanced MRI with single heartbeat temporal resolution is desirable for quantifying perfusion abnormalities. Current imaging protocols limit the ability to image the entire heart with single heartbeat temporal resolution, particularly at high heart rates. Multi-slice coverage may be achieved using saturation recovery with a relatively short preparation time (TI) and FGRE with echo-train readout [1]. Imaging quality may be improved at the expense of coverage [2] by increasing TI and readout flip angle. Alternatively, true-FISP imaging may be used with saturation recovery to produce high quality images without resorting to echo-train readout. The proposed method uses saturation recovery with a true-FISP readout, and uses accelerated imaging for greater spatial coverage.

METHODS

Imaging time may be reduced by under-sampled acquisition with full-FOV reconstruction using either UNFOLD [3] or parallel imaging methods such as SENSE [4]. The TSENSE [5] method was used to adaptively estimate B1-maps using an interleaved phase encode acquisition order. No additional temporal filtering for further alias artifact suppression was applied to the TSENSE images. Off-line reconstruction was performed in software using MATLAB (The Mathworks, Natick, MA.).

Imaging was performed on a 1.5T Siemens Sonata using a true-FISP sequence with the following typical parameters: TR=2.2ms (echo spacing), 50° readout flip angle, 1400 Hz/pixel BW, and 6 or 8mm slice thickness. Images were acquired from animal studies with infarct, as well as patient studies. For the results shown, images were acquired using a 5-element surface coil array for the dog study and 8-element array (Nova Medical, Wakefield, MA) for the human subject. For the dog study the acquisition matrix was 128x64 with FOV= 320x160 mm^2 corresponding to an in-plane resolution of 2.5x2.5 mm^2. For the patient study the acquisition matrix was 128x106 with FOV=340x340 mm^2 corresponding to an in-plane resolution of 2.6x3.2 mm^2. The TI was approximately 60 and 90ms for the dog and patient studies, respectively, where TI is defined at the center of *k*-space acquisition rather than to the 1st readout as in [1,2]. The imaging time per slice (including all overhead) was 100.5 and 158.9 ms for the dog and patient studies, respectively. The heart rate was 117 and 80 bpm for the dog and patient studies, respectively. The number of slices acquired per heartbeat was 4 for both studies.

SNR measurements were made in the mid-anterior-septal and mid-posterior myocardial regions using noise measured during prescan. Contrast-to-noise ratios (CNR) and contrast enhancement ratios (CER) were calculated from pre- and post-contrast SNR values. The SENSE g-factor was estimated from the pre-scan noise and estimated B1-maps.

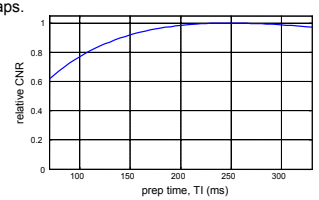

Figure 1. CNR versus TI for saturation recovery using true-FISP readout (normalized to maximum CNR).

The saturation preparation time (TI) determines the tradeoff between CNR, flatness of response (vs. phase encode), and spatial coverage. This tradeoff is illustrated in Figures 1 and 2 based on simulation. The magnetization during saturation recovery with a FISP readout was simulated for several values of T1 in the range 100-800 ms using the other experimental parameters listed. The CNR versus TI is plotted in Fig. 1 with the maximum CNR normalized to 1. Figure 2 (top row) plots the magnetization for saturation recovery versus pulse number (48 phase encodes for R=2 TSENSE) for selected values of TI (70, 90, 110, and 130 ms). The maximum number of slices that can be acquired per heartbeat corresponding to each TI is shown in Fig 2 (bottom row) based on 5% trigger window.

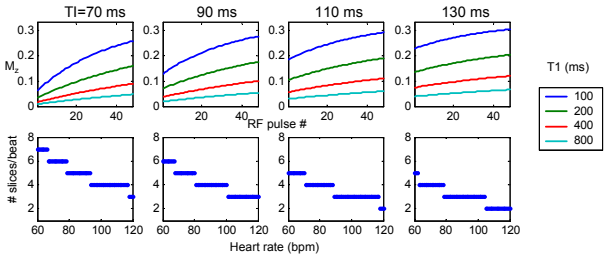

Figure 2. Magnetization recovery vs. readout pulse number (**top row**) for several T1 values at various preparation times (TI), and spatial coverage (**bottom row**) showing number of slices acquired per heartbeat vs. heart rate at corresponding values of TI.

RESULTS

Fig.3 shows example images of a single short axis (SAX) slice (of 4 acquired) during first pass perfusion for dog with occlusion in circumflex artery at following times: (a) pre-contrast, (b) RV enhanced, (c) LV enhanced, and (d) myocardium enhanced. The perfusion deficit in the region of occluded artery is clearly evident. The CNR between pre- and post-contrast for myocardium in the septal region was approximately 15 with a CER of approx. 3, and the post contrast CNR between normal and occluded region was measured to be approx. 13. Fig.4 shows example images of a single SAX slice (of 4 acquired) during first pass perfusion for a patient with acute MI at following times: (a) pre-contrast, (b) RV enhanced, (c) LV enhanced, and (d) myocardium enhanced. The CNR between pre- and post-contrast for myocardium in the mid-anterior-septal region was approximately 24 with a CER ≈ 2.2, and in the mid-posterior region the CNR ≈ 15 (CER ≈ 2.8). All images for each figure were window-leveled the same. The infarcted region may be seen in the delayed hyperenhancement images shown in Fig. 4(e). Note that the hyperenhancement images are not perfectly registered. FISP banding artifacts due to imperfect shim are evident in the posterior region of the apical slice. The R=2 SENSE g-factor estimated for the patient study using the 8-coil linear array was less than 1.1 in region of interest.

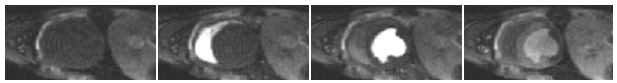

Figure 3. Example images of single SAX slice (4 slices per heartbeat acquired at 117 bpm) during first pass perfusion for dog with occlusion in CX artery: (a) pre-contast, (b) enhanced RV, (c) LV enhanced, and (d) myocardium enhanced.

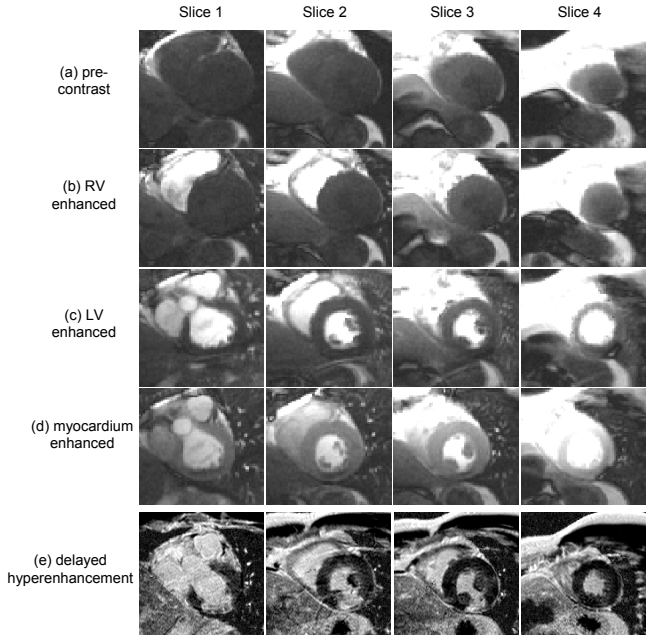

Figure 4. Example SAX images of SAX during first pass perfusion for patient with posterior MI (4 slices per heartbeat acquired at 80 bpm): (a) pre-contast, (b) enhanced RV, (c) LV enhanced, and (d) myocardium enhanced, and (e) delayed hyperenhancement images showing infarct region for comparison.

CONCLUSIONS

Multi-slice first pass perfusion true-FISP imaging with R=2 TSENSE acceleration has been demonstrated to achieve 2x spatial coverage with high quality image reconstruction. Reconstructions were performed using TSENSE without additional temporal filtering. Adaptive B1-map estimates were artifact free and SENSE alias artifacts were suppressed to the noise level or below. Higher accelerations factors may be possible for either increased coverage, higher spatial resolution, or operation at higher heart rates, although SNR will be reduced due to reduced acquisition time as well as an increased loss due to the SENSE g-factor. Further quantitative performance characterization is on-ongoing.

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