Introduction/ Purpose: Myocardial T1 mapping is commonly performed by pixel-wise curve fitting of single-shot images collected during diastolic rest period of cardiac cycle. Single-shot imaging often has limited spatial resolution, requires high acceleration factor and prone to cardiac motion that occurs over >200ms acquisition window during cardiac cycle. This results in partial volume error and reduced measurement precision in T1 mapping. We recently developed a free-breathing slice-interleaved T1 (STONE) [1] mapping sequence which removes the breath-holding constrain and allows efficient simultaneous imaging of multiple slices. In this study, we sought to further extend STONE imaging sequence to allow ECG segmented multi-shot data acquisition to improve spatial resolution. Phantom, ex-vivo and in-vivo experiments are performed to evaluate the proposed sequence.

Methods
Imaging Sequence: Fig. 1 shows the schematic of the proposed multi-shot STONE sequence, which consists of multiple inversion recovery (IR) prepared imaging blocks with segmented k-space data acquisition. To sample the infinity point of the longitudinal magnetization recovery curve, each slice is first acquired without any inversion pulse. In the averaged standard deviation of T1, in each slice is selectively excited after a single non-selective inversion pulse, and images are acquired over multiple cycles to acquire all k-space segments. This acquisition block is then repeated with different order of slices to sample the signal of longitudinal recovery curve at TI, TI + 1 RR, TI + 2 RR, TI + 3 RR, TI + 4 RR (TI: inversion time, RR: duration of one heart-beat), and finally repeated once more with different TI.

Experimental Validation: The proposed imaging sequence was implemented on a 1.5T Philips Achieva scanner. A phantom experiment was performed using 14 vials of NiCl2 doped agarose phantom with different T1/T2 times to verify accuracy, precision, and reproducibility of the segmented STONE T1 mapping sequence. Images were acquired five times repeatedly using the proposed multi-shot STONE (segmented bSSFP imaging readout, TR/TE=3/1.5ms, flip angle=35, FOV=280x322mm2, voxel size=1.5x1.5mm2, slice thickness=10mm, TFE shots=3, TFE factor=28, acquisition window=84ms, linear k-space ordering, 10 linear ramp-up pulses, SENSE factor=2) and compared to a single-shot STONE and a 5-(3)-3 scheme MOLLI [2] which were acquired using similar imaging parameters. Accuracy was defined as the difference between the mean T1 and the averaged reference T1 (spin echo) in each vial. Precision was defined as the averaged standard deviation of T1 in each vial. Reproducibility was defined as the standard deviation of T1 over five repetitions. Statistical significance between sequences were assessed using a Wilcoxon signed rank test. To demonstrate the feasibility of the proposed sequence, high-resolution T1 maps were acquired on ex-vivo heart of an infarcted swine model using the multi-shot STONE sequence (segmented bSSFP imaging readout, TR/TE=6/3ms, flip angle=35, FOV=160x160mm2, voxel size=0.5x0.5x0.5mm2, slice thickness=10, TFE shots=4, TFE factor=35, acquisition window=209.2ms, linear k-space ordering, 10 linear ramp-up pulses, SENSE factor=2) and compared to a single-shot STONE, but, higher accuracy (p<0.001) and reproducibility (p=0.005) with lower precision (p=0.034) compared to single-shot STONE.

Results: Phantom results show that multi-shot STONE has similar accuracy, precision, and reproducibility (p>0.05) compared to single-shot STONE, but, higher accuracy (p<0.001) and reproducibility (p=0.005) with lower precision (p=0.034) compared to MOLLI (Fig. 2). The high spatial resolution of the proposed segmented data acquisition allows detection of the myocardial scar in the post-Gd T1 map similar to high resolution T1 weighted images (Fig. 4). The high spatial resolution of the proposed segmented data acquisition allows detection of the myocardial scar in the post-Gd T1 map similar to high resolution T1 weighted images (Fig. 4). The high spatial resolution of the proposed segmented data acquisition allows detection of the myocardial scar in the post-Gd T1 map similar to high resolution T1 weighted images (Fig. 4).

Conclusion: The proposed segmented data acquisition for myocardial T1 mapping allows higher in-plane spatial resolution and reduces data acquisition window in each cardiac cycle which potentially reduces the partial voluming error in myocardial T1 measurement.

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