Single breath-hold 3D cardiac T$_1$ mapping

Yong Chen$^1$, Haris Saybasili$^2$, Alice Yang$^3$, Katherine L. Wright$^4$, Mark A Griswold$^{1,3}$, Vikas Gulani$^{1,3}$, and Nicole Seiberlich$^3$

$^1$Radiology, Case Western Reserve University, Cleveland, OH, United States, $^2$Siemens Healthcare, Chicago, Illinois, United States, $^3$Biomedical Engineering, Case Western Reserve University, Cleveland, OH, United States

Target Audience This work targets those interested in rapid measurement of relaxation times in cardiac tissues and in applications of non-Cartesian parallel imaging.

Purpose Cardiac T$_1$ mapping holds great potential for the detection of various cardiac diseases$^1$. In practice, due to cardiac and respiratory motion, measurement of T$_1$ values of heart can be extremely challenging, especially for quantitative analysis of the entire heart. Recently, a rapid and accurate single breath-hold 3D T$_1$ mapping method for the abdomen has been developed, using the Look-Locker technique in combination with through time spiral GRAPPA for acceleration$^2$. In this study, this strategy is modified with a segmented EKG triggered acquisition for cardiac application. GPU image reconstruction was also established for rapid image reconstruction, making the technique feasible for clinical applications.

Methods MRI experiments were performed on a Siemens 3T Skyra scanner with 32 receive channels. An algorithm similar to the modified Look-Locker inversion recovery (MOLLI) method was adopted for T$_1$ measurement$^3$. The scan was divided into two segments (two inversion recovery periods, each of four heart beats) with a pause of 4 sec between segments. In each inversion recovery period, the data acquisition was EKG-triggered and all the data were obtained during mid- to end-diastole. In the first segment, data acquisition started right after the inversion RF pulse, while in the second segment, a delay (400–500 ms dependent on the heart rate) was applied to achieve full coverage along the T$_1$ relaxation curve. This modified inversion-recovery Look-Locker method was combined with a stack-of-spirals trajectory and through-time non-Cartesian GRAPPA to accelerate data acquisition. To meet the Nyquist criterion, a total of 48 spiral interleaves in-plane are required. To accelerate the scanning, a reduction factor of six was used in-plane (only 8 arms were collected) and then reconstructed using 3D through-time non-Cartesian GRAPPA$^2$. To calculate the GRAPPA weights, a reference scan of twelve fully sampled 3D volumes (~43 sec) was acquired during free breathing, and was used for calibration along with a 4x1 segment size. Other parameters were: FOV= 44x44 cm; matrix size 224x224 for an effective in-plane resolution of 2.0 mm; TR 4.7 ms; TE 0.6 ms; flip angle 7°; slice thickness 8 mm; partial Fourier in the partition direction, 6/8. Overall, eight T$_1$-weighted 3D volumes were obtained with inversion times from 320 to 3600 ms and the acquisition time for each 3D volume was about 450 ms. The non-Cartesian GRAPPA image reconstruction and Fourier transform was performed using similar framework as for non-Cartesian radial GRAPPA with a single GPU card (NVIDIA Fermi M2090)$^4$. The GRAPPA weights calibration was achieved in approximately 90 sec and the image reconstruction for eight 3D volumes including filling missing interleaves using the GRAPPA weights and non-uniform FFT required approximately 20 sec.

The accuracy of the T$_1$ measurement was first validated using a manufactured phantom containing several vials with varying concentrations of GdCl$_3$ and agarose. T$_1$ values measured with an inversion-recovery single-echo spin-echo sequence (TR: 6 s; seven inversion times between 23 ms to 3000 ms) were used as the gold standard reference. After phantom validation, whole-heart T$_1$ mapping was performed on five asymptomatic volunteers in the short-axis view. The average acquisition time for T$_1$ mapping of the whole heart (16 slices) was 12.1±0.3 sec (12 heart beats in a single short breath-hold).

Results and Discussion Phantom results show that T$_1$ values acquired with the spiral sequence are in close agreement with the results from an IR spin echo sequence for a wide range of T$_1$ relaxation times from 400 to 1700 ms (Fig. 1). Fig. 1 shows representative T$_1$-weighted images along various points on the inversion recovery curve, and a corresponding T$_1$ map for a single slice from a volunteer. Representative whole-heart T$_1$ maps from another volunteer are shown in Fig. 3. The T$_1$ value of left ventricular myocardium from the five subjects was 1194±49 ms, which is in excellent agreement with the literature$^5$.

Conclusion In this study, a 3D whole-heart T$_1$ mapping technique was developed using the modified Look-Locker method, a stack-of-spirals trajectory and through-time non-Cartesian GRAPPA acceleration. This technique allows fast and accurate T$_1$ mapping of the whole heart in a single short breath-hold. The fast image reconstruction framework developed using a GPU makes this technique further feasible for a clinical setting.

References

Acknowledgements Siemens Healthcare and NIH grants R00EB011527, IR01DK098503 and SR01HL094557.