Single breath-hold 3D cardiac T_1 mapping

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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.

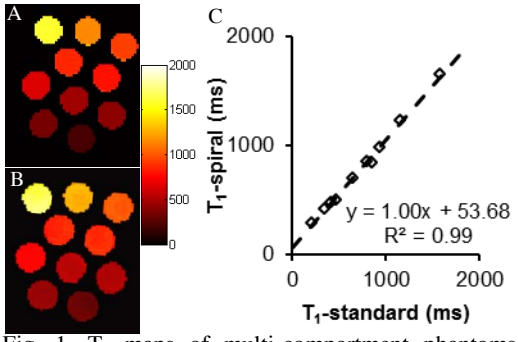

Fig. 1. T_1 maps of multi-compartment phantoms acquired using (A) inversion-recovery single-echo spin echo (TR: 6s) and (B) inversion-recovery stacks-of-spirals method. (C) Comparison of T_1 values from the two sequences.

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= 44×44 cm; matrix size 224×224 for an effective in-plane resolution of 2.0 mm; TR 4.7 ms; TE 0.6 ms; flip angle 7º; 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).

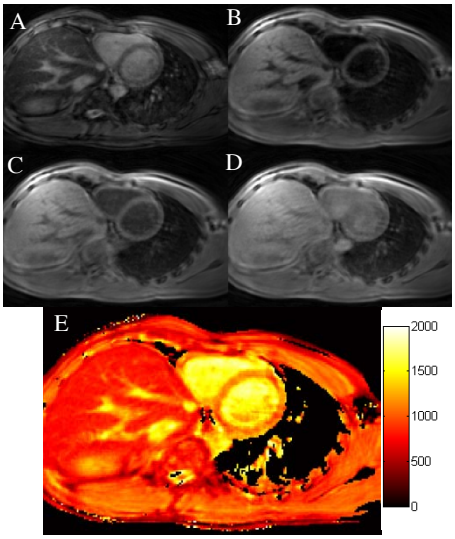

Fig. 2. (A-D) T_1-weighted images of a normal volunteer at different inversion times of 327, 919, 1428 and 3122 ms. (E) The corresponding T_1 map.

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. 2 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.

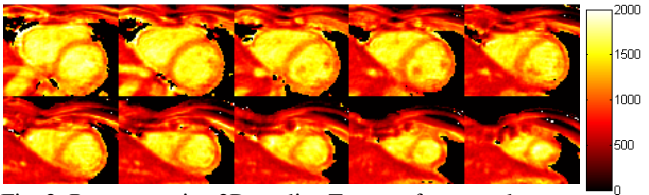

Fig. 3. Representative 3D cardiac T_1 maps from a volunteer.

References

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