

New Possibilities for Myocardial Strain Imaging using Acceleration and Iterative Reconstruction

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Introduction Myocardial Strain Imaging (MSI) offers great potential to quantify regional cardiac motion. The standard approach using a segmented cine FLASH tagging sequence provides dynamic displacement information by display of a deforming grid superimposed onto the anatomical image contrast. More elaborate approaches like CSPAMM [1], HARP [2] or DENSE [3] and SENC [4] overcome some of the limitations of standard tagging. However, spatial and temporal resolutions are typically still limited and the resulting image series only covers a single cardiac cycle (RR). Another limitation is the fading of the tag contrast at the end of the RR, resulting in low CNR for the diastolic phases. In this work, we explore the possibilities for MSI using higher PAT acceleration in combination with iterative reconstruction to regain CNR. Using a speed-up factor of 4 as compared to the unaccelerated standard method, we propose A) multiple incremental applications of the tag preparation in different cardiac phases to increase the tag contrast in the later phases, B) to cover two heartbeats after tag application to include a later heartbeat with virtually no tagging contrast to improve the quantitative strain analysis and C) to enable the estimation of a global T1 value from a tagging image series by covering multiple heartbeats.

Methods Accelerated MSI was employed based on a segmented FLASH grid tagging sequence with TPAT R=4, using an iterative reconstruction scheme based on L1-regularized wavelet approach [5, 6]. Measurements (TR 39 ms, matrix 192x150, FoV 340x280mm², tag spacing 7 mm) were performed in healthy volunteers (n=8) on a clinical 3T scanner (Magnetom Skyra, Siemens Healthcare, Erlangen, Germany), covering 3 parallel short-axis slices, each acquired in a short breathhold. Three different protocol variants were used: A) for incremental tagging, the tagging pulse was shifted to 3 different time points in the RR, for which the remaining phases were acquired individually (acquisition time (TA) 18 RR); B) for improved strain analysis, a protocol covering 2 RR was implemented (TA 12 RR) (fig. 1); C) for tagging combined with a global native T1 estimate, a protocol covering 3 RR with 3 additional recovery heartbeats between the segment readouts was used. As a reference, a standard tagging protocol (TA 20 RR, grid tag 8mm, TR 40 ms) was acquired and global T1 was quantified independently using MOLLI T1-mapping. CNR was evaluated for protocol A) using standard and iterative reconstruction and compared to standard tagging. Radial strain was calculated using the 2nd "NOTag" heartbeat as shown in fig. 1a by estimation of the deformation field and segmentation using a post-processing prototype (Siemens TruFi Strain V1.0) as shown in fig. 1b. T1 was estimated from protocol C) by segmentation of the LV myocardium and fitting a T1 saturation recovery model function to the signal intensities, taking into account a Look-Locker correction and an empirical factor for partial inversion of the tagging pulse.

Results The incorporation of iterative reconstruction significantly improved the image appearance and tag visibility in accelerated MSI (fig. 2). The use of protocol A) resulted in significant gain in tag persistence of 52±8% in the later cardiac phases. Figure 3 shows the average tag contrast-to-noise ratio (CNR) over time within the RR of a standard tagging protocol in comparison to the accelerated protocol with direct and iterative reconstruction. Strain analysis based on the deformation field derived from the 2nd heartbeat using protocol B) provided significantly higher radial strain values (31.2±8.2%) than typically found for standard tagging. Estimation of global native T1 based on approach C) resulted in a T1 decay that could be modeled with a modified SR function. Figure 4 shows the T1 relaxation curve derived from the tag fading over 3 heartbeats and the corresponding MOLLI T1 map.

Discussion and Conclusions Acceleration in MSI provides a new means to extend the quality and utility of the method. While highest accelerations enabling real-time performance may compromise the very high image quality demands for tag tracking, a moderate PAT acceleration of R=4 combined with iterative reconstruction seems to open up a variety of new applications towards more quantitative results in shorter breathholds, effectively lowering the barrier for MSI to become a widely used clinical tool. Besides the actual gain in CNR, incremental tagging extends the dynamic range of tag encoding as deformation of a given tag is limited to a subset of the cardiac cycle. The proposed extensions can easily be combined with more elaborate strain encoding techniques. More in-depth analysis of the proposed enhancements to MSI and application to patient groups are required to prove the ultimate clinical benefit.

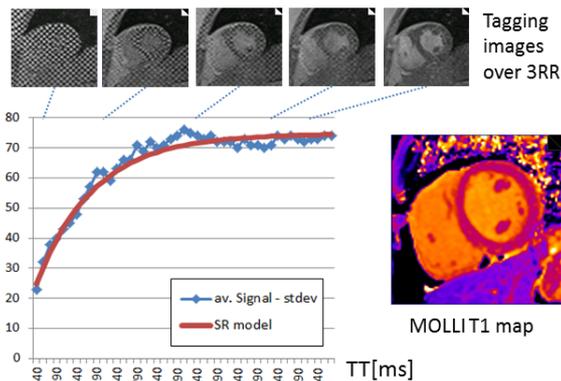


Fig.4: T1 Saturation Recovery relaxation curve derived from tag fading over 3 heartbeats and the corresponding MOLLI T1 map (T1 1227±65ms) in a volunteer.

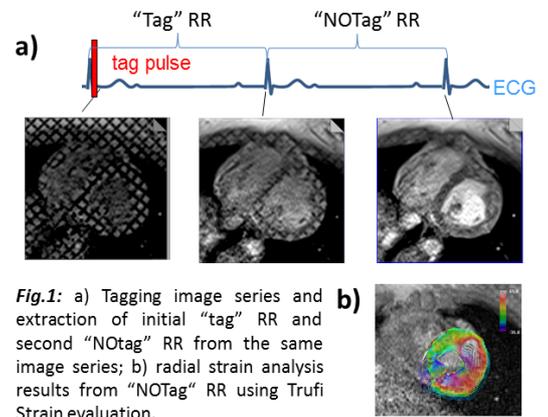


Fig.1: a) Tagging image series and extraction of initial "tag" RR and second "NOTag" RR from the same image series; b) radial strain analysis results from "NOTag" RR using TruFi Strain evaluation.

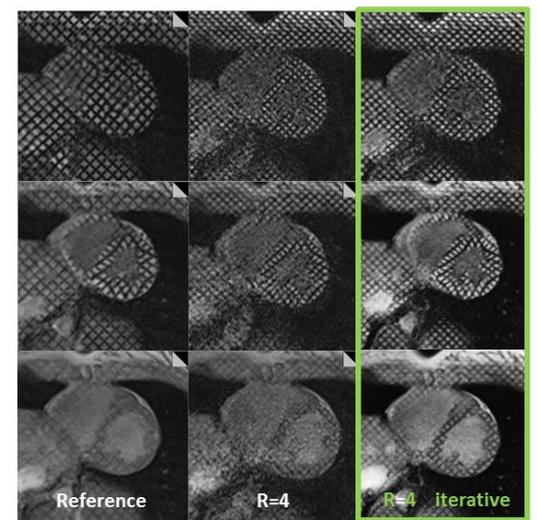


Fig.2: Tagging images for a) standard tagging acquisition; b) R=4 with direct reconstruction and c) R=4 with iterative reconstruction; top row: after R wave; middle row: systolic phase; bottom row: diastolic phase.

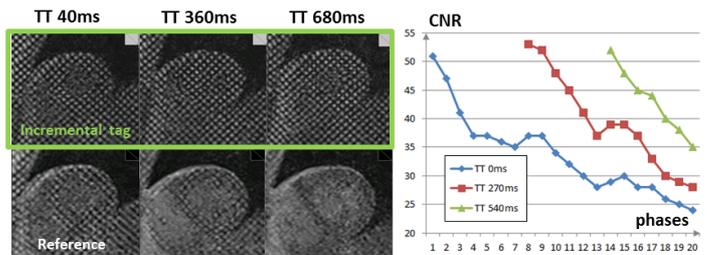


Fig.3: Contrast-to-noise levels of standard and incremental tag image series for different trigger times (TT); upper left: incremental tag images; bottom left: standard tagging; right: CNR as a function of cardiac phases for tags played out at different tag times.

References

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