Spiral DENSE with short breath hold duration

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Introduction:
Recent advances in acquisition technique using DENSE (Displacement ENcoding with Stimulated Echoes) have allowed us to reach scan times of a single breath hold for in-plane displacement mapping [1, 2]. Spiral acquisition offers additional flexibility in trading scan time for image quality, as fold-over artifacts are not as severe in spiral sampling as compared to Cartesian sampling. DENSE is commonly acquired using CSPAMM or N-SPAMM subtraction in order to reduce artifacts, however, this makes the technique inherently sensitive to breath hold drifts during the acquisition. It is therefore important to limit the breath hold duration of the acquisition. The aim of this study was to determine feasibility and accuracy of an imaging setting with substantially reduced scan time.

Methods:
By reducing the number of spiral interleaves, the acquisition of a single image can be performed in a single cardiac cycle. Combined with three acquisitions for 3-SPAMM elimination of artifacts [3] and three acquisitions with different encoding directions for elimination of phase errors, a total imaging duration of 9 RR intervals is achieved. This is compared to a two-cardiac cycles per image acquisition which results in a scan time of 18 RR intervals.

Ten healthy volunteers (10 male, age 30.1±5.36 years old, heart rate 66.6±7.95 bpm) were imaged in a clinical 3T MRI system (Achieva, Philips, Best, The Netherlands). After localization scans, 9 and 18 RR interval DENSE acquisitions were performed in randomized order in three left ventricular short axis levels. The pulse sequence parameters were selected as follows: field-of-view 240 mm, matrix size 80x80, voxel size 3x3 mm, slice thickness 3 mm, balanced [4] inplane displacement encoding 0.25 cycles/pixel (0.083 cycles/mm), throughplane displacement dephasing 0.2 cycles/pixel (0.033 cycles/mm), optimized flip angle for constant maximum SNR [5]. Water-selective excitation was used in the 1-1 SPAMM preparation, in order to obtain fat-free signal after N-SPAMM reconstruction. The time of end systole for each subject was determined visually from a cine image sequence. From this time, 55 ms was subtracted, and from there five phases with 55 ms interval were acquired. Signal reception was performed using a 32 element cardiac coil. For the 18RR acquisition, six interleaves with 8 ms duration spiral trajectories were used, for a TE/TR of 1.0/11 ms. Three interleaves were acquired each cardiac cycle. For the 9RR acquisition, four interleaves with 10 ms duration spiral trajectories were used, for a TE/TR of 1.0/13 ms, all acquired in a single cardiac cycle.

Images were analyzed in in-house developed software. Lagrangian E_2 strain was computed in every pixel. A semi-automatic segmentation was used to divide the three slices into 16 segments according to the AHA standard. The Lagrangian E_2 strain was averaged on a per-segment basis and compared pair wise between the 18 RR and the 9 RR acquisitions. Bland-Altman analysis was used to determine bias and 95% limits of agreement.

Results:
All images were acquired successfully. Lagrangian E_2 strain maps in one of the volunteers are presented in Figure 1. There is no noticeable difference in image quality between 18RR and 9 RR acquisitions. Figure 2 demonstrates the correlation and Bland-Altman plots for the per-segment Lagrangian E_2 strain values obtained using both acquisitions. The bias between the two methods (18 RR - 9 RR) for quantifying Lagrangian E_2 strain was 0.000, with the 95% limits of agreement of ±0.04. Peak strain was -0.20±0.03 for both the 18RR and the 9RR acquisition.

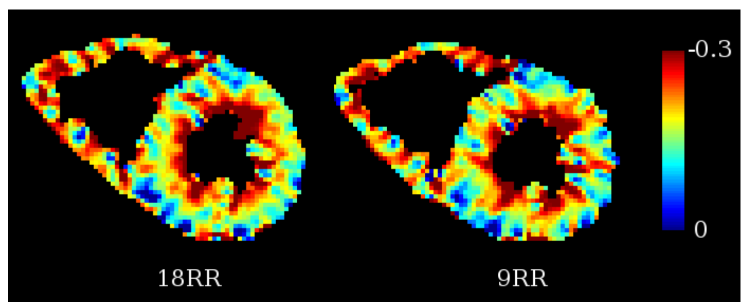

Figure 1. Lagrangian E_2 strain maps from one of the volunteers for 18 RR and 9 RR acquisition in the midventricular level.

Discussion:
By reducing the number of spiral interleaves, DENSE images can be acquired in a significantly shorter breath hold. There was good agreement between Lagrangian E_2 strain acquired in 18 and 9 RR intervals, indicating that the 9RR acquisition can be used without much difference in segmental strain values. This can be very valuable for DENSE imaging of patients which have trouble holding their breath for 18 RR intervals, and may enable the applicability of DENSE for stress imaging which is especially demanding for breath holding. Additionally, the technique may improve success rate for DENSE imaging of patients with severe heart disease.

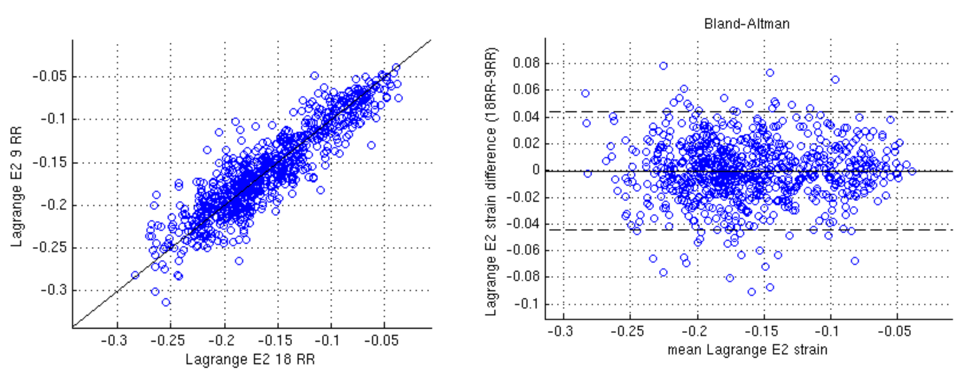

Figure 2. Left: Correlation between segmental Lagrangian E_2 strain obtained using 18RR and 9RR acquisitions is high (r=0.90, $p<0.001$). The black line is the identity line. Right: Bland-Altman plot showing low bias (solid line), and 95 % limits of agreement (dashed lines, ±1.96 std.dev.)

References:
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3. Tsao et al., ISMRM 2005:273
4. Stuber et al., MAGMA 1999;9(1):85-91
5. Zhong et al., MRM 2009;61:981-988