Comparison of Accelerated Velocity Encoded MRI with SENSE and kt-BLAST in a Beating Heart Phantom

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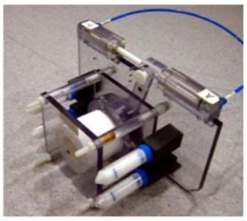

Figure 1 : Image of a heart phantom

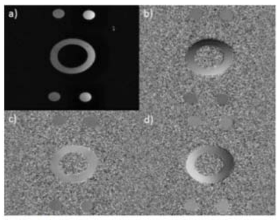

Figure 2: MR images of heart phantom approx 130 ms after the trigger; a) magnitude image; b-d) velocity encoded images in AP, FH and RL direction

Introduction: For a detailed analysis of myocardial motion high temporal and spatial resolution is required. To avoid unacceptable long acquisition times, rapid imaging techniques have to be applied. In this contribution kt-BLAST and SENSE are compared in a beating heart phantom regarding the preservation of the velocity data in velocity encoded myocardial imaging at different degrees of acceleration. The highly reproducible motion curve of the heart phantom enables the quantitative comparison of the different techniques under reproducible conditions. All quantitative data is compared to the motion curves obtained by the non-accelerated technique.

Materials and Methods: The phantom cup was made of a mixture of 90% polyvinyl alcohol (PVA, Lenticats, GeniaLab, Braunschweig, Germany), 10 % agarose (Serva tables). 3 µl Fe contrast agent (SHU 555C, Schering AG, Berlin, Germany) were added to mimic T2 relaxation constants of the myocardium. This mixture was filled into a cylindrical mold and two freeze/thaw cycles at -35°C/+20°C were used. The cylindrical phantom was placed in a MR-compatible air-pressure actuator (Figure 1), which rotates the phantom according to a preset heart rate [1]. The phantom generates an ECG signal, which was used for synchronization of the MR scanner. To modulate different motion curves of the phantom, the pressure curve was modulated by a frequency generator sending a triangle, square, sine or ramp pulse, thus producing different pressure curves. 4 static reference PVA tubes were placed next to the phantom cylinder and used for background-phase error correction.

Image acquisition was performed on a 3T whole body MR scanner (Achieva 3.0T, Philips, Best, The Netherlands) with a 32 [2x4x4] channel phased array cardiac coil. A coil-sensitivity reference scan was acquired for obtaining the coil sensitivity profiles, which were required for the SENSE reconstruction. The TPM acquisition was performed applying a segmented and velocity encoded phantom triggered gradient echo sequence. The acquisition parameters were: TE/TR = 4.3ms/6.7ms, flip angle = 15°, spatial resolution = 2x2x8 mm^3, 3 k-lines per segment and one startup segment. Isotropic velocity encoding of 20cm/s was performed in a Hadamard fashion by a four-point velocity vector method [2]. 2 examinations were performed for each pressure/motion curve. The following data sets were acquired for each pressure/motion curve: 2 without acceleration, SENSE accelerating factors R = 2-7, and kt-BLAST accelerating factors R = 2-7.

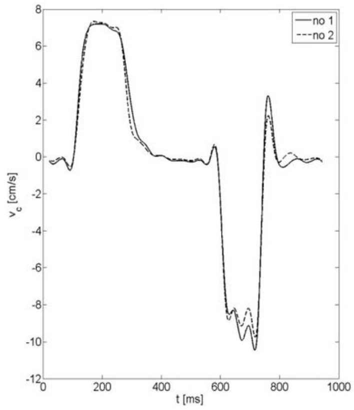

Figure 3: Circumferential velocity for two scans without acceleration obtained by a square pressure form.

The PVA-agarose-iron ring was segmented automatically by an active-contour technique in all data sets. Background phase error correction was performed using a bilinear fit to the phase of the reference tubes. The rotational motion, systolic and diastolic peak velocities, and the velocity range (difference of peak velocities) were calculated from each data set. The peak factor PF, defined as the ratio of velocity ranges obtained with and without acceleration, was calculated. The quality of the resulting motion curves was further quantified by the normalized root mean square deviation (nRMSD(seq.1, seq.2)) and the correlation coefficient (c(seq.1, seq.2)).

Results: Figure 2 shows the magnitude and velocity encoded images of the heart phantom 130 ms after the start of the motion cycle. Figure 3 shows the reproducibility of the obtained circumferential velocity curves exemplarily for the motion generated by a square pressure actuation curve. The mean nRMSD, correlation coefficient and peak factor of the circumferential motion for the different acceleration factors are provided in figures 4a-c.

The correlation coefficient obtained by kt-BLAST is significantly (p-value <= 0.05) smaller than the reproducibility for all acceleration factors. No significant decrease of the correlation coefficient is obtained by SENSE with R = 2-5, whereas a significant decrease was obtained for SENSE with R = 6, 7. For identical acceleration factors, SENSE reveals higher correlation coefficients than kt-BLAST (significant for R = 2-4; 7).

The nRMSDc obtained by kt-BLAST is significant (p-value <= 0.05) higher than the nRMSD of the reproducibility measurement for all acceleration factors. No significant increase of nRMSDc was obtained for SENSE with R=2-4; 6; 7. For identical acceleration factors, SENSE reveals significant smaller nRMSDc than kt-BLAST.

The PFc obtained by kt-BLAST is significant (p-value <= 0.05) smaller than the PFc of the reproducibility measurement for all acceleration factors. No significant decrease of PFc was obtained for SENSE for all acceleration factors. For identical acceleration factors, SENSE reveals significant higher PFc than kt-BLAST.

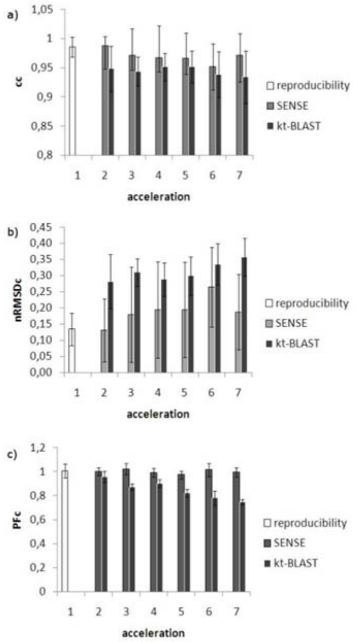

Figure 4: Mean correlation coefficient, nRMSD and PF for the circumferential motion for the reproducibility study, SENSE acceleration and kt-BLAST acceleration.

Discussion and Conclusion: In this contribution, the application of SENSE and kt-BLAST for velocity encoded myocardial MRI was tested in a heart phantom. The highly reproducible motion of the phantom enabled quantitative comparison of the techniques. The results indicate a superior performance of SENSE for preservation of the peak velocities, peek factor and motion curves. No significant differences were observed for SENSE up to an acceleration factor of 4. Higher SENSE factors can likely be obtained in combination with 3D imaging techniques.

In conclusion, this phantom study reveals that SENSE should be favored over kt-BLAST to accelerate tissue phase mapping.

References: [1] Manzke et al. ISMRM 2010, #3778; [2] Pelc et al. J Magn Reson Imaging 1991; 1: 405-413