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Joint Reconstruction of DCE Abdominal Images

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Purpose: An abdominal dynamic contrast enhanced (DCE) examination typically consists of a series of five or more images acquired with the same imaging sequence, FOV, and resolution during multiple breath-holds. The resulting images represent the same anatomy, but differ due to contrast agent arrival and wash-out. The time constraints, posed due to restricted breath-hold duration and contrast arrival, necessitate parallel imaging. Compressed sensing (CS) can potentially improve the temporal and spatial resolution of such image series[1] further. Different approaches for CS in dynamic imaging were previously proposed, for example low rank and sparse matrix decomposition[2]. These approaches were primarily tailored to dynamic cardiac imaging. However, in abdominal DCE, the contrast agent injection can make it more difficult for the patient to hold their breath properly, resulting in severe artifacts after contrast injection. Data are acquired with a modified adaptive sampling pattern[3], which implies higher undersampling for shorter breath-holds. The post-contrast images should, therefore, benefit from a joint reconstruction of pre- and post-contrast images.

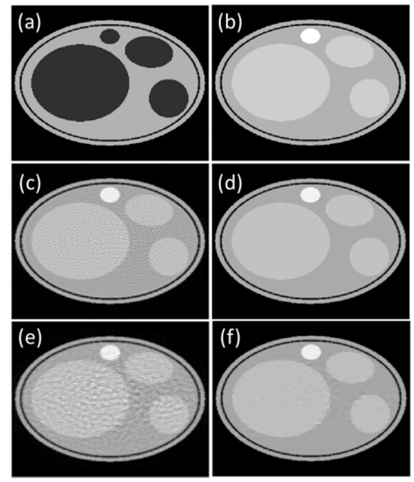

Fig.1: Images from simulated phantom data. (a) pre-contrast phantom image, (b) post-contrast, (c,d) post-contrast with R=8 and reconstructed using (c) L1-ESPIRiT, and (d) JointL1-ESPIRiT. (e,f) post-contrast with R=16 and reconstructed using (e) L1-ESPIRiT, and (f) JointL1-ESPIRiT. Improvement is obvious for high reduction factors.

Methods: For the reconstruction of post contrast images, L1-ESPIRiT[4] was used with a modified optimization function that takes the similarity of contrast wash-in/wash-out phases into account.

$$\min_{\boldsymbol{m}} \sum_i \left\| y_i - PF\sum_j S_i^j m^j \right\|_2^2 + \alpha \sum_j \left\| \sqrt{\sum_k \beta_k \left|\Psi m_k^j\right|^2} \right\|_1^2$$

This minimization problem contains the k-space data y, the current estimation of the image m, the index i sums over coils, j over image components, and k over temporal phases, F is the Fourier transform operator, P the undersampling operator, S contains the coil sensitivities, Ψ the wavelet transform, α is a regularization parameter and β a weighting factor. The first term enforces data consistency, and the second term enforces joint sparsity of the distinct temporal phases. The weighting factor β enables variation of the influence of the phases, which can lead to improvement in case of an outstanding phase. With decreasing number of profiles available for reconstruction, the undersampling artifacts become worse and potentially hide significant wavelet coefficients. If more profiles are acquired for one dataset, the aliasing is less severe and coefficients are preserved. If they occur at the same position in the different phases, also these coefficients will be preserved with the presented optimization problem in highly undersampled phases. This already implies that the improvement has a strong dependence on the quality of the best phase. Simulated 2D phantom data for pre- and post-contrast images (k=2) were undersampled with a distinct variable density Poisson disk sampling pattern and reconstructed using L1-ESPIRiT and the joint approach. To investigate the dependence on the reference image, the RMSE for R=4 and R=8 was calculated for different undersampling factors of the pre-contrast image. Volunteer and patient data (n=5) were acquired on a 3T scanner (Achieva, Philips Healthcare, Best, The Netherlands) using a 16-element torso coil. In addition to a clinical DCE series, two images were acquired: one before contrast injection and one directly after the clinical dynamic study. A T_1-weighted spoiled dual-gradient-echo mDIXON sequence with a $TE_1/TE_2/TR$ of 1.13/2.0/3.7ms was employed to cover a typical FOV of 340×262×300 mm^3 with an acquired spatial resolution of 1.5×1.5×3.0 mm^3. An adaptive sampling pattern was used that copes with premature breathing onset by enabling flexible scan termination. A central area in k-space is fully sampled first, followed by partially sampling the periphery. In the periphery, samples are acquired according to a variable density Poisson Disk distribution for incoherent aliasing enabling a CS reconstruction at any point in time.

Pre- R / Post- R	1	2	4	8	L1-ESPIRiT
4	3.11	3.48	3.66	3.54	3.78
8	4.16	4.47	4.77	5.72	6.37

Tab.1: RMSE in percent of original image. RMSE of post contrast result for R=4 or 8 relative to fully sampled image. Dependence on reduction factor of reference pre-contrast image is visible with constantly reduced RMSE for the joint approach.

Results: Reconstruction results for the simulated phantom data are given in Fig.1. For reference, images with R=1 are given in (a) for pre- and (b) for post- contrast images. (c,e) are reconstructed from post-contrast data with (c) R=8 and (e) R=16 using L1-ESPIRiT, and (d,e) are reconstructed with the joint approach using pre-contrast image with R=1. While the reconstruction with R=8 (d) has nearly unaffected image quality for the Joint approach, the L1-ESPIRiT reconstruction (c) is degraded, which is even more apparent for R=16 in (e,f). Table 1 summarizes the RMSE for R=4 and R=8. The RMSE worsens for increasing reduction factor of the reference image, while an improvement is visible with the joint reconstruction compared with separate reconstruction. Volunteer data are given in Fig.2. While (a) is reconstructed from data acquired in the first 27s, (b,c) are reconstructed from the first 16s using L1-ESPIRiT (b) and the joint approach (c). Compared with the 27s scan, the RMSE is (b) 249.8 and (c) 247.6, which correspond to (b) 3.1% and (c) 3% deviation, showing a slightly reduced error.

Discussion: Phantom simulations and indicate superior reconstruction results for the joint reconstruction of pre- and post-contrast images compared with pure L1-ESPIRiT reconstruction. For in vivo data, the error relative to the 27s post-contrast scan is only slightly reduced for the joint reconstruction. The improvement is strongly dependent on the quality of the pre-contrast image and the geometric alignment of the phases. Furthermore, the phantom simulations indicate that the joint approach is especially helpful in extreme cases, where separate sparsity fails. Larger improvement for in vivo data is expected for higher undersampling. This work shows that joint approaches can potentially improve image quality in DCE abdominal imaging in patients with insufficient breath-hold capability.

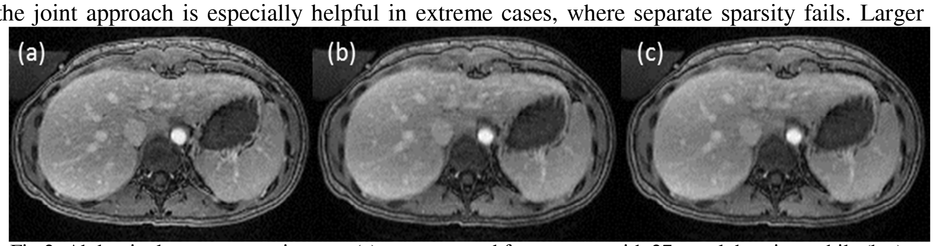

Fig.2: Abdominal post-contrast images. (a) reconstructed from a scan with 27s total duration, while (b,c) retrospectively truncated to 13s and reconstructed with (b) L1-ESPIRiT, and (c) JointL1-ESPIRiT .

References: 1. Gamper U, et al. MRM 2008:365-73. 2. Otazo R, et al. ISMRM 2012: 4248. 3. Gdaniec N, et al. ISMRM 2012: 600. 4. Uecker M, et al. MRM 2013: published online