Assessment of image reconstruction methods for subsampled DCE-MRI

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Introduction: The reliable identification of pharmacokinetic parameters requires high resolution DCE-MRI data sets in spatial and temporal domain. High field systems in combination with undersampled imaging techniques like HYPR or parallel imaging have the potential to deliver those images. It is, however, not clear to which extent these techniques change the time course of contrast enhancement, in particular for the arterial input function. This work evaluates the performance of four different fast imaging methods.

Methods: A simple software phantom was designed to simulate the change of contrast during the passage of a contrast agent bolus in different tissue regions. Simulated tissues were artery (top left circle), vene (bottom left circle), tumor (bottom right circle) and gray matter (background) (**Fig.1**). For simulation, a typical arterial input function (interpolated) was taken from independent measurements. The extended Kety-model [1] was used for pharmacokinetic modelling (Tumor: Fp=1.2 ml/(min ml), blood volume (bv)=0.08 ml/ml, K^{trans} =0.296 ml/(min ml), vl=0.4; Gray matter: F=0,54 ml/(min ml), bv=0.04 ml/ml, K^{trans}=0). Sequence parameters were TR=3ms, TE=1.2ms, FA=25°, Matrix Size (x,y,z) = 128x128x20. Acquisition with an 8 channel head coil was simulated, and Gaussian noise was added prior to the reconstruction. High SNR was chosen, in order to show the direct influence of the reconstruction methods on the signal time course more clearly. Images were subsampled in the xy-plane. Reconstructions were performed with tGRAPPA [2] (R=4, Δt=1.92s, ACS lines were constructed using a sliding window of four adjacent timeframes, 32 were included during the reconstruction), HYPR [3] (HYPR frame: 16 projections, corresponding to an acceleration factor of approximately 13, sliding window composite: 128 projections, Δt = 0.96s), PROBER [4] (R=4, ACS=32, Δt=3.42s), and with an iterative reconstruction using a total variation constraint of an undersampled radial scan, following the compressed sensing (CS) approach of [5] (20 projections, Δt = 1.2s). An unaccelerated scan with the same sequence parameters had a Δt of 7.68s. All reconstructions were done with MATLAB.

Results:

Image quality was quantified using SNR, estimated with the "difference method" [6], and the RMS difference to an unaccelerated reference image. Best image quality was achieved with HYPR and CS, while residual aliasing artifacts were visible in tGRAPPA and PROBER. The difference at the peak of the AIF was calculated for all reconstruction methods. Arterial time courses of PROBER, HYPR and CS showed high temporal fidelity. Deviations could be seen in the tGRAPPA reconstruction, especially during the first pass of the contrast agent (**Fig. 2**). Tumor time courses were very accurate in all reconstructions (**Fig. 3**). Contrast agent concentration images were calculated, and the mean value and standard deviation of K^{trans} were evaluated in the region of the tumor tissue. All accelerated scans resulted in compareable estimations for K^{trans}, but the temporal resolution of the unaccelerated scan was too low to provide a reasonable result. The results are summarized in **Table 1**.

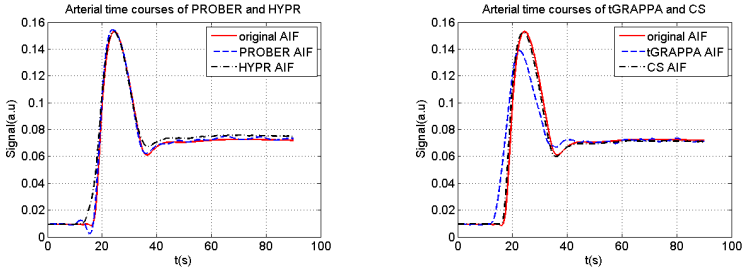

Fig. 2: AIF: Original signal, and results of PROBER and HYPR (left), and of tGRAPPA and CS (right) reconstructions. First 90s are shown.

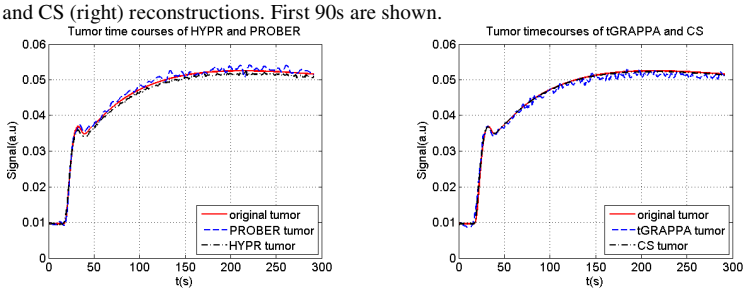

Fig. 3: Tumor signal: Original signal, and results of PROBER and HYPR (left), and of tGRAPPA and CS (right) reconstructions.

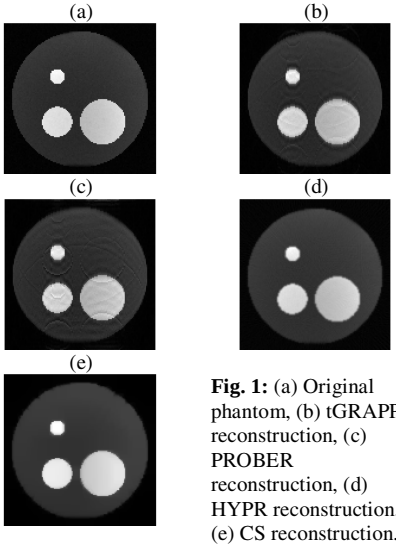

Fig. 1: (a) Original phantom, (b) tGRAPPA reconstruction, (c) PROBER reconstruction, (d) HYPR reconstruction, (e) CS reconstruction. The last timeframe of the simulation is displayed.

Discussion: Undersampled imaging techniques provide the temporal resolution for pharmacokinetic analysis. In comparison to the unaccelerated scan, the evaluation of K^{trans} was significantly better for all undersampling methods. Especially the performance of HYPR was surprisingly good, because the phantom was designed with gray matter as background tissue. Therefore, the background had a completely different signal time course than the arterial or tumor region, which is usually a bad scenario for the HYPR algorithm. Both HYPR and CS reconstructions had high SNR, no visible artifacts, and a very accurate representation of the signal intensity changes. When using tGRAPPA, the inclusion of ACS lines in the reconstruction increased image quality, but this resulted in temporal averaging, which led to a less accurate representation of the arterial time course.

Reconstrucion	SNR (dB)	RMS diff. (a.U.)	AIF deviation (%)	K^{trans} (ml/(min ml))
Unaccalerated	33.86	-	10.60	0.384 ± 0.007
HYPR	41.60	0.07	1.83	0.308 ± 0.009
tGRAPPA	32.96	0.11	13.18	0.270 ± 0.009
Compressed sensing	41.76	0.09	1.35	0.308 ± 0.004
PROBER	31.33	0.13	2.76	0.277 ± 0.016

Table 1: Quantitative evaluation of all reconstruction methods.

References: [1] Tofts et al., JMRI, 10: 223-232 (1999) [2] Breuer et al., MRM 53: 981-985 (2005) [3] Mistretta et al., MRM: 55: 30-40 (2006) [4] Petr et al., MRM 58: 582-591 (2007) [5] Lustig et al., MRM, 2007, submitted [6] Reeder et al., MRM 54: 748-754 (2005)