Comparison of SENSE and *k-t* SENSE in Dynamic Imaging

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Introduction

Parallel data acquisition has proven invaluable for a range of dynamic imaging applications. Typically, reductions factors between 2 and 4 are achieved in most practical situations and at clinical field strengths. Beyond this limit, increasing local noise enhancement severely degrades image quality. With the wider availability of larger coil arrays, the problem may be partially counteracted within the limits given by electrodynamic considerations [1]. In dynamic imaging, parallel image reconstruction can be improved by considering spatial and temporal encoding in a joint manner. By deliberately shifting phase encode lines for different time points, temporal spectra can be displaced to reduce aliasing among significant signal components [2,3]. This approach is particularly effective in conjunction with a model or estimate of the spatial and spectral signal distribution. In *k-t* SENSE [3], such an estimate is derived from low-resolution training data sampled at the full temporal bandwidth.

The objective of this work was to compare *k-t* SENSE with conventional SENSE in dynamic imaging with up to 24 independent coil elements. Furthermore, it is demonstrated that *k-t* SENSE permits a flexible trade-off between the temporal fidelity and the signal-to-noise ratio (SNR) of reconstructed dynamic data sets. Highest temporal fidelity is achieved by fully exploiting sensitivity encoding, whilst for higher SNR the reconstruction relies more on the training data.

Methods

Cardiac gated cine balanced SSFP 2D images of the heart were acquired on a Philips 1.5T system (Philips Medical Systems, Best, The Netherlands) using a prototype 32 channel coil array. Data from the 24 coil elements covering the heart were recorded and processed off-line to generate undersampled data sets simulating 5-fold and 8-fold accelerations with 20 and 24 cardiac phases, respectively. In *k-t* SENSE, the seven central profiles of the fully sampled *k*-space were used as training data. The undersampling patterns were designed to provide maximum main-lobe separation of signal replica in *x-f* space [4] (Figure 1). At the same time, these patterns allowed for self-calibration by using the time-averaged signals for coil sensitivity determination. SENSE and *k-t* SENSE reconstructions at 5- and 8-fold acceleration using 8, 16, and 24 coil elements were compared relative to a fully sampled dataset by means of the relative root-mean-square error metric. The most sensitive 8 and 16 coil elements with respect to the region of interest were selected to form coil subsets. Finally, the temporal response of *k-t* SENSE reconstruction was modified using constant offsets added to the *x-f* filter, i.e. the reconstruction equation was modified to $\boldsymbol{\rho} = (\alpha\mathbf{I}+\mathbf{M}^2)\,\mathbf{S}^H(\mathbf{S}(\alpha\mathbf{I}+\mathbf{M}^2)\mathbf{S}^H + \boldsymbol{\Psi})^+\boldsymbol{\rho}_{alias}$, where $\mathbf{S}$ is the sensitivity encoding matrix, $\boldsymbol{\rho}$ and $\boldsymbol{\rho}_{alias}$ are unaliased and aliased signal vectors, $\mathbf{M}^2$ contains the prior information, $\boldsymbol{\Psi}$ denotes the noise covariance, and $\alpha\mathbf{I}$ is a diagonal matrix with constant offsets added to the prior information. Thereby, the influence of coil encoding was gradually increased in an attempt to recover small signals at high temporal frequencies at the expense of amplified noise.

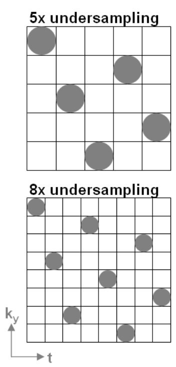

Figure 1. Sampling pattern in k-t space for factors 5 and 8.

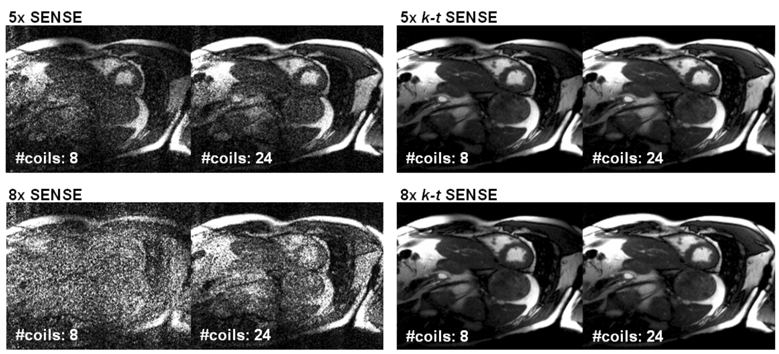

Figure 2. Self-referenced SENSE and k-t SENSE reconstructions of short-axis images of the heart for reduction factors 5 and 8 using 8 and 24 independent channels. Frames during rapid motion in early diastole are shown.

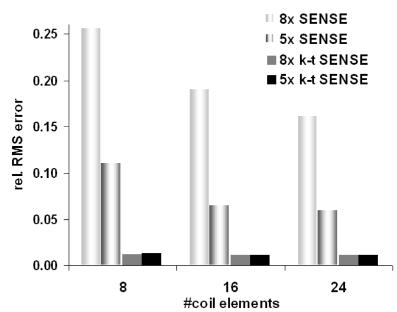

Figure 3. Relative reconstruction error as a function of the number of coil elements for SENSE and k-t SENSE.

Results

Figure 2 compares SENSE versus *k-t* SENSE reconstructions at 5- and 8-fold acceleration using 8 and 24 coil elements. Image quality of 8x SENSE is severely compromised by local noise amplification whereas excellent image quality is achieved with *k-t* SENSE. Relative RMS errors are summarized in Figure 3. Figure 4 compares the temporal fidelity among the fully sampled data, standard *k-t* SENSE reconstruction, and *k-t* SENSE with a constant offset of 1% of the maximum signal added to the *x-f* filter. It is seen that temporal fidelity of *k-t* SENSE can be improved by offsetting the *x-f* filter (Figure 4c).

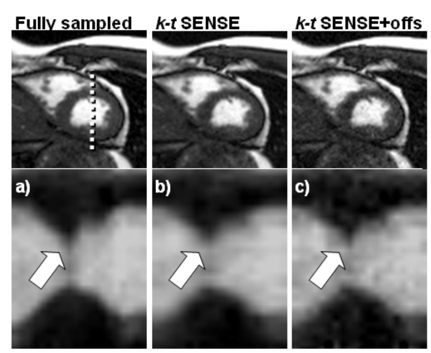

Figure 4. Comparison of temporal fidelity. Short-axis slice (upper row) with signal intensity over time along dotted line (lower row) for fully sampled scan (a), 5x k-t SENSE (b) and 5x k-t SENSE with constant filter offset (c).

Discussion

k-t SENSE outperforms SENSE at high acceleration factors, even when large coil arrays are used. *k-t* SENSE offers a flexible means to shift the balance from prior knowledge as provided by the training data towards coil encoding, depending on whether low noise amplification or recovery of small signals at high temporal frequencies are of importance in a certain application. The optimal balance for each application remains a subject of further studies.

The authors thank Marc Kouwenhoven, Tom Rozijn and Hans Tuithof from Philips Medical Systems for their assistance during the measurements.

References

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