Accelerating Time-resolved 3D Contrast-enhanced Angiography Using *k-t* BLAST

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Introduction

Dynamic information about arterial filling and venous enhancement upon contrast injection may provide additional information about vascular conditions. High-resolution dynamic MR angiographic approaches such as time-optimized view sharing [1] or keyhole in conjunction with parallel imaging [2] have been demonstrated. Nevertheless, limited acquisition speed usually requires a trade-off between spatial and temporal resolutions. Recently, a new class of reduced data acquisition schemes has been introduced for dynamic imaging, called *k-t* BLAST and *k-t* SENSE [3]. These techniques exploit redundant information present in time-resolved data of natural objects. This redundancy can be visualized by transforming the temporal dimension (*t*) of a time-resolved data set into its temporal frequency domain (*f*) (Figure 1). From the *x-f* representation, it becomes apparent that only a fraction of the available data space is actually used to encode information. It is this particular sparseness of the data which makes time-resolved contrast-enhanced angiography an ideal candidate for undersampling strategies. In *k-t* BLAST, *k*-space positions and time are undersampled, leading to denser packing of signal replica in the reciprocal *x-f* domain. Hence, the available data space is used more effectively. In reconstruction, potential aliasing of signal replica is resolved using dynamic, low spatial resolution information obtained simultaneously during the undersampling stage. This work aims at incorporating the *k-t* BLAST framework into keyhole imaging with elliptic shutters for accelerated dynamic contrast-enhanced angiography.

Methods

A time-resolved reference data set was obtained using the CENTRA keyhole method [2] on a Philips 1.5T system (Philips Medical Systems, Best, NL) during administration of 20 ml of a Gd chelate at a rate of 1.5 ml/sec. Imaging parameters were: matrix: 256x230x33, spatial resolution: 1.5x1.4x2.4 mm^3, T_R/T_E: 2.7/1.0 ms, flip angle: 30°, scan time per dynamic frame: 3.5 sec. The data were then processed off-line to generate undersampled data sets according to Figure 2 simulating 8x and 16x *k-t* BLAST acquisition of the keyhole section including a densely sampled elliptic region for training [4]. Taking the acquisition of training data into account, net simulated speed-up factors were, 5.6 and 8.6 for 8x and 16x *k-t* BLAST, respectively. Prior to *k-t* BLAST reconstruction, the time-invariant portion of the images as obtained from the keyhole reference was subtracted in *k*-space to reduce signal intensity at zero temporal frequency. Data from multiple coils were combined after image reconstruction using root-mean-square combination. Maximum intensity images were generated for the reference and the *k-t* BLAST reconstructions. For comparison, the undersampled data were also reconstructed using sliding window reconstruction with the training data plugged back after reconstruction.

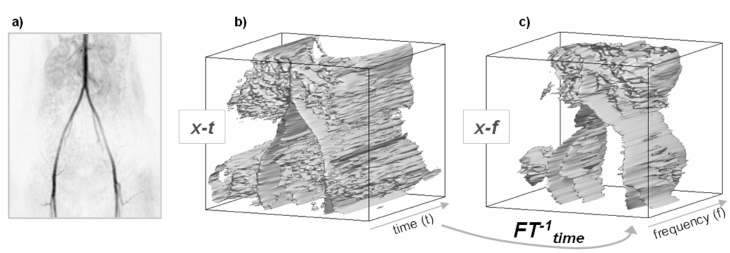

Figure 1. Maximum intensity projection image of the pelvic arteries at filing (a). Depiction of signal evolution over time using an x-t plot (b). By applying an inverse Fourier transform along time, signal distribution in the spatial-temporal frequency domain is obtained (c). In this plot, image information is represented in a compact fashion with large areas of the data space left unused.

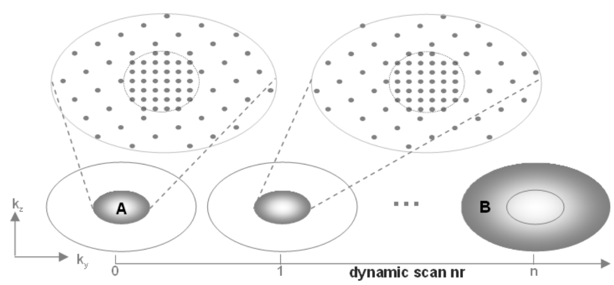

Figure 2. k-t BLAST keyhole imaging scheme. The central elliptical portion (A) is repeatedly sampled along a sheared grid including a densely sampled region for training. Full k-space data are acquired after dynamic acquisition. The outer rim (B) is plugged back into the low resolution dynamic frames prior to image production.

Results

Comparison of time-intensity curves at particular locations along the vessel tree revealed good temporal agreement between the reference and the 8x *k-t* BLAST acquisition (Figure 3). At 16x *k-t* BLAST acceleration, temporal blurring increases significantly. Nevertheless, at both simulated acceleration factors, *k-t* BLAST reconstructions outperform conventional sliding window reconstruction at 8x acceleration.

Discussion

The *k-t* BLAST method presents a potential add-on to further accelerate time-resolved contrast-enhanced keyhole angiography. In contrast to SENSE acceleration, *k-t* BLAST can operate with as few as a single receiver coil. While in the current approach, data from multiple receive coils were combined after reconstruction, future extension to *k-t* SENSE will incorporate coil sensitivity information to reduce residual image artefacts. At the current point, temporal blurring of time variant signals at acceleration factors greater than 8 presents a practical upper limit for *k-t* BLAST acceleration.

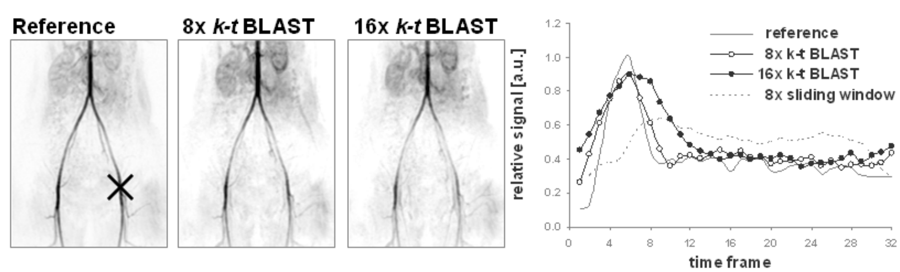

Figure 3. Exemplary time frames acquired at peak filling using CENTRA keyhole imaging (reference) and 8x and 16x k-t BLAST of the elliptical keyhole portion. Signal-time curves at the location as indicated by the black cross are shown relative to the time curve extracted from the reference scan. For comparison purposes, the signal time curve derived from conventional view sharing (sliding window) reconstruction of the 8x undersampled scan is given (dashed curve).

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References

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