Accuracy of Cerebral Blood Flow Measurements in Accelerated Dynamic Contrast Enhanced MRI using *k-t* SENSE

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INTRODUCTION: Quantification of cerebral blood flow (CBF) using bolus-tracking MRI plays an important role in the diagnosis and treatment of vascular and degenerative diseases of the brain. In conventional dynamic susceptibility contrast (DSC) MRI [1], as well as in dynamic contrast enhanced (DCE) MRI [2], the need for a short image sampling time compromises spatial resolution and/or spatial coverage. The image acquisition of both techniques can be accelerated by a factor of 2-3 using parallel imaging techniques, such as SENSE [3], whereas EPI is only compatible with DSC-MRI due to the inherent T2*-weighting. The more recent *k-t* BLAST technique achieves high acceleration factors in dynamic MRI by exploiting spatial and temporal correlations jointly [4], and it has the added advantage that it can be combined with both EPI and SENSE [4]. It remains unknown, however, how the inherent temporal filtering [5,6] of *k-t* BLAST affects CBF measurements. This study investigates how different degrees of data reduction obtained with *k-t* BLAST and *k-t* SENSE affect CBF measurements using DCE-MRI.

THEORY: *k-t* BLAST speeds up the data acquisition by undersampling *k*-space over time (referred to as *k-t* space). The resulting aliasing is resolved in the Fourier reciprocal *x-f* space using an adaptive filter, calculated from a set of low-resolution training images. Since the contrast bolus passage cannot be imaged more than once, the training data and undersampled data must be acquired in tandem, as described in Ref. [7]. The size of the training data, which consist of a few central phase-encoding lines sampled for each point in time, therefore represents a trade-off between lowering the net acceleration factor and improving the quality of the training data [6]. It has been shown for cardiac cine imaging that 11 training profiles represents a good trade-off [6]. Although the accuracy of the reconstruction can be improved by reusing the acquired training profiles (referred to as *training plug-in* [6]), *k-t* BLAST reconstruction in its basic form remains an underdetermined problem. By incorporating SENSE (i.e., *k-t* SENSE) the reconstruction problem becomes an overdetermined one, provided that the number of receive coils exceeds the acceleration factor. Therefore, it is expected that *k-t* SENSE causes less temporal filtering than *k-t* BLAST, which may in turn yield more accurate CBF maps.

METHODS: We performed simulations based on a fully sampled DCE-MRI data set acquired in a patient who had undergone operation and radiotherapy of a primary brain tumor. The data set was acquired on a 3.0 Tesla MR scanner (Intera Achieva, Philips Healthcare, Best, The Netherlands) equipped with an eight-element receive coil. We used a saturation recovery prepared spoiled gradient echo sequence, as described in detail in Ref. [2]. Two slices were acquired with a matrix size of 96×96, an FOV of 240×240 mm^2, and 180 dynamics. The saturation recovery delay was set to 120 ms, resulting in a temporal resolution of approximately one frame per second. In the simulations, the fully sampled *k*-space data were undersampled and reconstructed with *k-t* BLAST and *k-t* SENSE using acceleration factors ranging from 2 to 16 and with the training size set to 3, 11, and 21. All reconstructions were performed with and without training plug-in. For the CBF calculation, we used model-independent deconvolution, as described by Ostergaard et al. [1]. The arterial input function was measured in the right internal carotid artery (corresponding to the healthy brain hemisphere). The CBF values are presented on a relative scale, and the CBF errors are reported in % relative to the reference CBF.

RESULTS: Figure 1 shows the CBF maps and CBF errors for *k-t* BLAST and *k-t* SENSE using 8x acceleration and 11 training profiles. As expected, the overall CBF error is smaller for *k-t* SENSE than for *k-t* BLAST, but both techniques benefit from using training plug-in. Therefore, we focused mainly on *k-t* SENSE with training plug-in.

Figure 2 shows the average CBF error for *k-t* SENSE with training plug-in. The CBF error is plotted for all combinations of acceleration factor and training size, with a separate curve for each training size. In general, increasing the acceleration factor and/or decreasing the training size increases the CBF error. These data suggest that in order to keep the CBF error well below 20%, the acceleration factor should not exceed 8, and the training size should be 11 or larger. Interestingly, below 8x acceleration there seems to be no major difference in CBF error between using 11 and 21 training profiles. As demonstrated in Fig. 3 for the arterial input function, this is because the signal intensity vs. time curves with 11 and 21 training profiles (and 8x acceleration) are almost identical. Since the latter only yields a net acceleration factor of 3.2, the ideal setup in this patient is *k-t* SENSE with training plug-in, 8x acceleration and 11 training profiles, resulting in a net acceleration factor of 4.6.

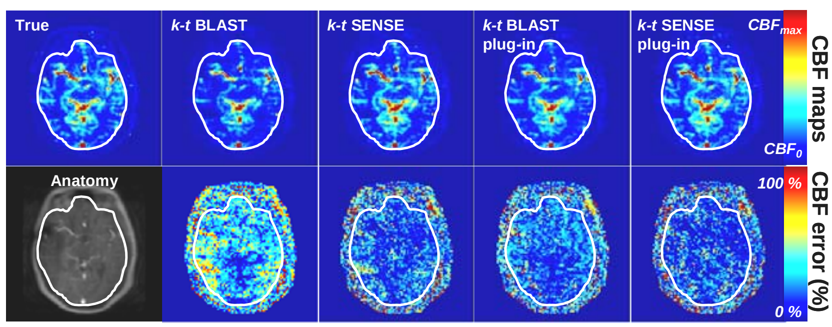

FIG 1. Example CBF maps and CBF errors for 8x acceleration and 11 training profiles. The CBF values are presented on a relative scale, and the CBF error is given in %. The outer contour of the brain has been highlighted for better visualization. In this patient, the CBF map for *k-t* SENSE with training plug-in is nearly identical to the reference CBF.

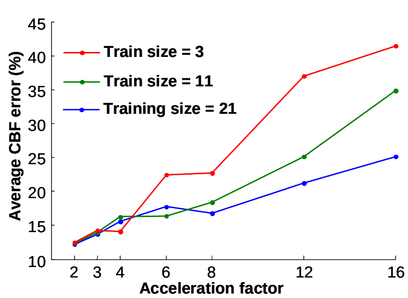

FIG 2. Average CBF error using *k-t* SENSE with training plug-in for various training sizes and acceleration factors. To keep the error well below 20%, the acceleration factor should be 8 or smaller and the training size 11 or larger.

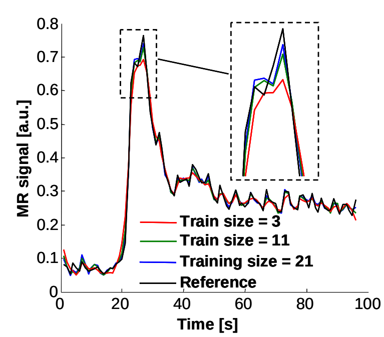

FIG 3. Arterial input function (AIF) for *k-t* SENSE with 8x acceleration and training plug-in. With 3 training profiles, the AIF is clearly low-pass filtered. Both for 11 and 21 training profiles, the AIF is nearly identical to the reference.

CONCLUSIONS: The assessment of CBF using bolus-tracking MRI benefits from accelerated imaging, as long the acceleration does not significantly reduce the accuracy of CBF measurements. The preliminary results of this study show that *k-t* SENSE with training plug-in can accelerate DCE-MRI by a factor of 4.6, while keeping the average CBF error well below 20%. In practise, this allows increasing the spatial coverage of DCE-MRI from 4 slices with SENSE [2] to about 10 slices with *k-t* SENSE. The accuracy of *k-t* SENSE depends on the acceleration factor and training size. This study confirms what has previously been shown for cardiac cine imaging [6], namely that there is little gain in increasing the training size above 11 profiles. Further patient studies have been planned to more accurately determine the optimum setup for *k-t* SENSE in DCE-MRI.

REFERENCES: 1) Ostergaard et al. MRM 1996, 2) Larsson et al. JMRI 2008, 3) Pruessmann et al. MRM 1999, 4) Tsao et al. MRM 2003, 5) Tsao et al. MRM 2005, 6) Hansen et al. MRM 2004, 7) Kozerke et al. MRM 2004.