High Resolution Dynamic-Susceptibility Contrast Perfusion Imaging Using Multi-Echo Parallel EPI

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Introduction

In dynamic-susceptibility contrast-based magnetic resonance imaging (DSC-MRI), time series are acquired during the first pass of an intravascular tracer. From these dynamic scans, it is possible to estimate cerebral blood volume (CBV). Furthermore, from pixel-wise deconvolution with an arterial input function (AIF) yields maps of cerebral blood flow (CBF) and mean transit time (MTT) [1, 2]. There are several benefits of using a multi-echo (ME) approach for DSC-MRI [3-5]: 1) ΔR_2^*, which is assumed to be proportional to tracer concentration, can be measured undisturbed from T_1 enhancement caused by the tracer (e.g. in the presence of a blood-brain-barrier disruption). 2) Without the need for a pre-bolus baseline signal, the method becomes less sensitive to large-scale signal instabilities and patient motion. 3) Automatic selection of arterial input function [6, 7] can be based on the first echo which has the appropriate dynamic range (high tracer concentration) and the least artifacts (signal voids). 4) If the dynamic range using ΔR_2^* of all echoes is too small to estimate the AIF in arterial voxels because of a large signal drop, the procedure can be limited to the first echo(es) [5], for example by a magnitude-weighted exponential fit.

In combination with parallel imaging (PI), a high spatial and temporal resolution can be achieved [8]. In addition, PI reduces image artifacts related to EPI. We will refer to this technique, i.e. the combination of ME with PI, as PERfusion with Multiple Echoes and Temporal Enhancement (PERMEATE).

Materials and Methods

All scans were performed on a 1.5 T scanner (Signa LX/i, GE Medical Systems, Waukesha, WI) fitted with high performance gradients (maximum strength: 50 mT/m, rise time: 270 μs). PI was performed by means of an eight-element coil together with 2 different reduction factors: R=3 and R=4. A multi-echo multi-slice gradient-echo EPI sequence was implemented to image 15 slices (5-mm thickness, 1-mm gap) with 240-mm FOV and a matrix size 96 $\times$ 96. The number of echoes equals the reduction factor. Sequence parameters were: TE = 13.8, 31.6, 49.4 ms (R=3) and TE = 12.4, 27.3, 42.2, 57.1 ms (R=4), 100 repetitions with TR = 1225 ms, $\pm$ 100 kHz receiver bandwidth and a flip angle of 70°. Image reconstruction was performed by a GRAPPA-based algorithm [9]. A single dose of 0.1 mmol/kg Gd-DTPA was administered at a rate of 4 ml/s followed by 20-ml saline flush. After converting signal magnitudes to ΔR_2^* time series, perfusion maps were calculated by a block-circulant singular-value decomposition for tracer arrival timing-insensitive deconvolution [10] with a tolerance threshold p_{SVD} = 10 % using an automatically selected AIF [7] from the first echo. As a measure of accuracy of the method, the ratio of CBF and CBV between gray and white matter was estimated by values within manually drawn regions-of-interest.

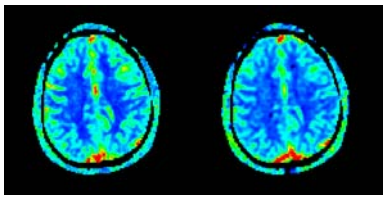

Figure 1: CBF (left) and CBV (right) maps of a 32-year old healthy volunteer, acquired with R = 4.

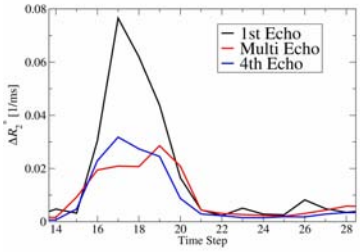

Figure 2: AIF obtained from 1st echo, 4th echo and by multi-echo fit (R = 4).

Results

As an example, Fig. 1 displays perfusion maps of a healthy volunteer obtained by PERMEATE. Gray and white matter can be very well delineated. The AIFs shown in Fig. 2 demonstrate that the first echo has the most appropriate dynamic range for AIF selection and was hence used for further CBV/CBF analysis. Gray/white matter ratios of two subjects are shown in Table 1. The values and their age-dependency are in good agreement with previously reported values [1].

Discussion and Conclusions

PERMEATE allows robust, accurate, and distortion-reduced high-resolution estimation of ΔR_2^* and the AIF which is the basis for CBV/CBF calculation. It can be expected that, due to the advantages of ME acquisition mentioned above, quantitative CBF and CBV calculations become more accurate.

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R	Age (y)	CBF_{GM}/CBF_{WM}	CBV_{GM}/CBV_{WM}
4	32	2.8 ± 0.5	2.9 ± 0.3
3	32	3.0 ± 0.5	3.3 ± 0.7
4	50	2.4 ± 0.2	2.5 ± 0.3

Table 1: Gray/white matter ratios of CBF andCBV in two different healthy volunteers of