Comparison of different algorithms for minimizing macro vessel signal in cerebral perfusion imaging

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INTRODUCTION: Dynamic-Susceptibilty-Contrast Magnetic Resonance Imaging (DSC-MRI) has been established as a reliable method to investigate hemodynamic changes in cerebral perfusion. Compared to PET and SPECT, DSC-MRI often overestimates of the amount of cerebral blood flow (CBF) and cerebral blood volume (CBV), which is due to the high sensitivity of DSC-MRI to large vessels [1]. To improve the correlation between DSC-MRI data and PET, a method referred to as ELV has been proposed. It consists of a defined threshold that is applied to CBF or CBV images to eliminate large vessel (ELV) signal [2]. Another ELV approach is based on a cluster analysis of the perfusion parameters to separate vessels from other tissue [3]. However, the ELV method does not take partial volume effects (PVE) into account and perfusion parameter maps suffer from the large number of excluded pixel. Carroll et al. [4] proposed a method to eliminate large vessel signal and reduce partial volume effects in DSC-MRI data using independent component analysis (ICA). The ICA method has been shown to be robust with regard to differences in temporal resolution and signal-to-noise ratio of the DSC-MRI time-series [5]. In this work we set out to compare the hemodynamic parameters CBF, CBV and the mean transit time (MTT) for uncorrected perfusion data with ELV and ICA vessel artifact corrected data.

METHOD: In-vivo DSC-MRI data were obtained from ten patients with high-grade unilateral symptomatic stenosis of the internal carotid artery. Measurements were performed on a 3.0T MRI scanner (Siemens Tim Trio, Siemens Medical, Germany) with an 12 channel head coil (Siemens Medical, Germany). A Single Shot EPI sequence was used with the following parameters: FOV/TR/TE/α=230mm/1250ms/28ms/60° with an image matrix of 128x128, slice thickness of 5.4mm and a temporal resolution of 1.19s for 19 slices and 60 time points. A dose of 0.1 mmol/kg contrast agent (DOTAREM®, Guerbet, France) was injected intravenously via a power injector (Spectris; Medrad Inc., Indianola, PA, USA) at a rate of 5 ml/s, followed by 30 ml of NaCl 0.9% at the same speed.

ICA was applied on DSC-MRI data using the FastICA algorithm [6] to solve the linear problem $x = As$, where x is the measured dynamic time series, A the mixing matrix and s the set of independent components. To minimize the influence of large vessel signal in perfusion data independent components (ICs) which represent macro vessel signal have to be identified. ICs are automatically classified as artifactual based on similarity measurements between the calculated ICs and the overlap between the arterial and venal flow patterns in the DSC-MRI data. The identified ICs are removed from the data set by setting the ICs to zero. Afterwards the ICA back transformation step is performed. As a result a dynamic perfusion time series is obtained were the influence of macro vessel signal is minimized [5]. An ELV method was applied based on clustering of multiple parameters derived from the dynamic contrast-enhanced first-pass curve [3].

To minimize the influence of slice positioning on hemodynamic parameter maps, the perfusion images of each patient were spatially normalized into the standard MNI space (Montreal Neurological Institute) using SPM 8 software (Wellcome Department of Imaging Neuroscience, London, UK). The transformation matrix was stored and applied to the corrected dynamic time series. This procedure ensured that uncorrected and corrected perfusion data are located within the same space and makes it possible to evaluate perfusion parameters in the same slice for the entire group. DSC-MRI data of eight patients were analyzed for a central slice ($z = 16$).

The perfusion analysis and the large vessel artifact removal were performed with nordicICE software (NordicNeuroLab AS, Bergen, Norway). The hemodynamic perfusion parameters CBF, CBV, and MTT were calculated using the singular value deconvolution (SVD) method. To generate semi-quantitative perfusion maps, a fixed internal reference value of normal perfused frontal white matter CBF=22 ml/100g/min was used to scale the AIF [7]. Only the normally perfused hemisphere was evaluated in this study.

RESULTS: To investigate the ability of different methods for reducing large vessel signal in perfusion parameter maps, we compared the mean CBF, mean CBV and mean MTT values for uncorrected data, ICA corrected data and ELV corrected data (Table 1). A two-tailed t-test with a significance level of $P<0.05$ revealed a significant reduction of mean CBF (19%), mean CBV (19%) and mean MTT (4%) in grey matter tissue in the ICA corrected perfusion data. We also found a significant reduction using the ELV method for mean CBF (34%), mean CBV (38%) and mean MTT (26%) in grey matter tissue. No significant changes were found in white matter tissue for CBF and CBV and MTT for both correction methods, indicating that the ICA correction as well as the ELV correction successfully reduced large vessel artifacts specifically in cortical grey matter. Figure 1 show CBF, CBV and MTT maps for one patient in a central slice. Note the artifacts due to pixel elimination using the ELV method (third column).

Table 1: Quantitative results for perfusion parameters CBF (ml/100g/min), CBV (ml/100g) and MTT (s) for original DSC-MRI data, for ICA macro vessel corrected DSC-MRI data and for ELV corrected DSC-MRI data. The results of the descriptive statistics are reported as mean ± 1SD for white matter tissue (WM) and for gray matter tissue (GM).

	ORG		ICA		ELV	
	GM	WM	GM	WM	GM	WM
CBF	53.4 ± 13.0	23.0 ± 2.5	43.1 ± 9.2	23.1 ± 3.2	35.1 ± 8.2	22.8 ± 2.5
CBV	5.9 ± 2.0	2.5 ± 0.4	4.8 ± 1.6	2.5 ± 0.6	3.6 ± 0.9	2.5 ± 0.4
MTT	5.3 ± 1.0	5.4 ± 0.7	5.1 ± 1.1	5.2 ± 0.8	3.9 ± 1.0	5.3 ± 0.7

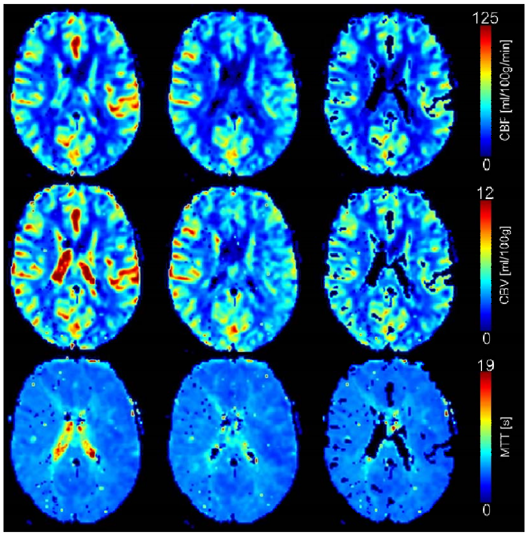

Figure 1: Hemodynamic parameter maps CBF (first row), CBV (middle row) and MTT (last row) for uncorrected DSC-MRI data (first column), for ICA macro vessel corrected DSC-MRI data (second column) and for ELV corrected DSC-MRI data (third column).

CONCLUSION: In this work we compared two different methods with regards to minimize macro vessel signal in hemodynamic parameter maps. It has been shown, that both methods, the ICA correction and the ELV correction, successfully reduce artificial elevated signal specifically in cortical grey matter in CBF and CBV parameter maps. The quantitative CBF and CBV values of the ICA method are in excellent agreement with CBF values obtained by positron emission spectroscopy [1]. CBF and CBV values of the ELV corrected data show a trend to underestimate cerebral perfusion. The reason for this underestimation is due to the large number of excluded pixel. Excluded pixel also impairs the image quality of parameter maps and worsens the perceptibility of anatomical structures. These results indicate that the ICA method has some advantages over the ELV method and should be preferred for minimizing macro vessel signal in DSC-MRI data.

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