Reduction of Vascular Artefacts in Arterial Spin Labeling using Principal Component Analysis of Vessel Timeseries

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Introduction

Arterial spin labeling (ASL) is a non-invasive perfusion measurement technique that is based on the subtraction of tag and control image pairs. Due to the small perfusion-related ASL difference signal, large arteries often give high-signal artefacts in ASL difference images. This artefact may be positive or negative depending on various imaging parameters and may extend to neighbouring voxels. The vascular signal may be reduced using vascular crushers in the acquisition [1], but this is usually insufficient in larger arteries around the circle of Willis, i.e. the middle and posterior cerebral arteries and the posterior communicating arteries. This artefactual signal poses problems for perfusion quantification, especially in ROI analysis or smoothed ASL images. Another approach is to filter out pulsation-induced effects using RETROICOR [2,3], but this requires external recording of physiological data. We propose a method for reducing the vascular artefacts by including principal components of the vessel timeseries as covariates in a general linear model (GLM) analysis of the ASL timeseries.

Methods

PICORE QUIPSS II [4] measurements were performed on 12 healthy subjects (age=68-84 years, 6 male) on a 3T Siemens Magnetom Trio scanner with a gradient echo EPI readout. Imaging parameters were: ten axial 5 mm slices covering the temporal lobe, $TI_1/TI_2/TR/TE$ =700/1700/2250/20 ms, 64x64 matrix, FOV=192 mm, 140 repetitions. The measured timeseries were realigned to the first image using SPM2. A GLM (model 1), $Y=X_1\beta+\varepsilon_1$, was fitted to the full timeseries, Y, where X_1 is the design matrix with the following regressors: a constant term to model the mean signal, a tag/control difference term which was $[-1\ 1\ -1\ 1\ ...]^T$, 24 regressors forming a Volterra expansion of the 6 realignment parameters [5] to model residual motion effects and 4 regressors forming a discrete cosine transformation of a high pass filter created in SPM2 (cutoff frequency=1/128s). The parameters β were estimated and a vessel map was formed by including voxels where the standard deviation (STD) of the residuals was within the top 1% fractile. Principal component analysis (PCA) was performed on the timeseries of the vessel voxels and components explaining more than 5% of the variance each were included in an extended design matrix, X_2, whose other regressors were those included in X_1. A new GLM (model 2), $Y=X_2\beta+\varepsilon_2$, was then fitted to the data giving perfusion estimates with reduced vascular artefacts.

Results

The ASL maps of 7 subjects exhibited medium to large vascular artefacts around the circle of Willis. Fig.1 shows the STD maps of the ASL timeseries. Areas with a high STD coincide with large vessels, but also extend to neighbouring voxels. Fig.2 shows the standard mean ASL difference images (top row) with vascular artefacts in the same areas with a high STD in Fig. 1.The bottom row shows the β values corresponding to the tag/control difference regressor in X_2. It is clear that the vascular artefacts are strongly reduced using model 2. All 7 subjects with medium to large vascular artefacts on the simple subtraction scheme showed a substantial reduction in the artefact using model 2. For the remaining 5 subjects with small or no artefacts there was no change (2), a small increase (2) or a small decrease (1) in the artefact.

Discussion

Including the main principal components of large vessel timeseries as nuisance regressors in a GLM of the ASL timeseries strongly reduces the vascular artefacts in baseline perfusion images as demonstrated in this study. The vessel timeseries are automatically extracted from the STD maps of the residuals of model 1. The STD maps of the ASL difference timeseries are very similar to the maps used, but may contain a portion of edge voxels due to respiration effects, especially in higher slices (data not shown). These are, however, often removed by the high-pass filter included in both models.

Our approach is different from that proposed by Behzadi et al. [6] in that our method takes advantage of the difference between large vessels and tissue in the noise magnitude, thereby restricting the PCA to vascular timeseries. The proposed method is, however, fully expandable to reducing respiratory effects as well. These are predominant in higher slices, where STD-based masks include more edge voxels. The method is also applicable to perfusion fMRI studies, especially studies involving the temporal lobes.

References

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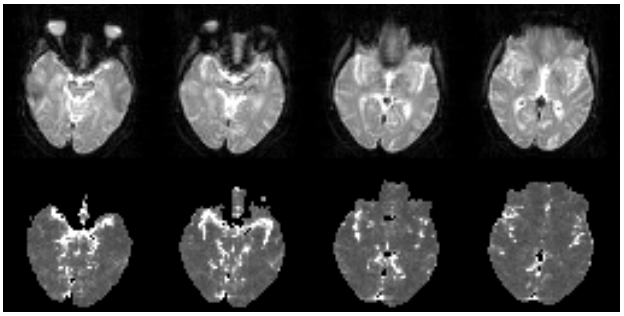

Figure 1. Anatomical EPI images of 4 slices from one subject (top row) and STD maps of the residuals from the model 1. The STD maps are used to find a vascular mask.

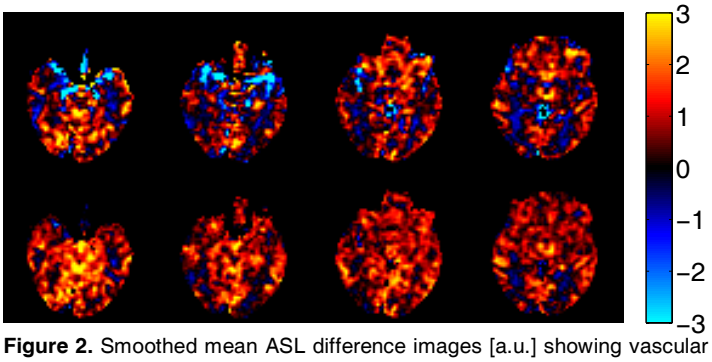

Figure 2. Smoothed mean ASL difference images [a.u.] showing vascular artefacts with large negative values (top row) and the corresponding difference images calculated using model 2 (bottom row).