# An Independent Component Analysis Approach for Removing Recirculation in Perfusion Weighted Images

Y. Wu[1], H. An[2], H. Krim[1], W. Lin[2]

[1]Department of Electrical Engineering, North Carolina State University, Raleigh, NC, United States, [2]Department of Radiology, University of North Carolina, Chapel Hill, NC, United States

## Introduction

Dynamic susceptibility contrast (DSC) approaches have been widely utilized in the study of tissue perfusion. By acquiring images rapidly prior to, during and after the injection of a contrast agent, the temporal signal changes induced by the presence of contrast agent can be obtained, which typically consist of the baseline signal, the first passage and the recirculation of contrast agent. In DSC perfusion weighted imaging (PWI) approaches, the temporal signal curves are converted to concentration time curves and effects of recirculation need to be removed prior to the estimation of cerebral blood flow (CBF) and cerebral blood volume (CBV). The concentration curves are normally fitted to a gamma variate function in an attempt to remove recirculation. However, this approach has several drawbacks. First, important physiological information might be compromised by imposing a common analytic equation to all measured concentration curves. Second, this approach will only work in cases that the first passage can be well separated from the recirculation. When cerebral hemodynamics is compromised such as cerebral ischemia, a substantially broadened concentration curve is anticipated, leading to the first passage inevitably overlapping with recirculation. Under such a condition, the currently available approaches are unlikely to offer a consistent means for discerning contributions of recirculation from the first passage. Therefore, an alternative method is desired.

Independent component analysis (ICA) is a widely used method for blind source separation, i.e., to determine underlying independent signal sources from observed data without any prior knowledge of the sources [1-2]. In this investigation, we propose to use ICA to remove recirculation from the concentration curves assuming that the first passage and recirculation can be distinguished as different components regardless whether these two are overlapped. Our results demonstrate that the reconstructed concentration curves after removing the components contributed by recirculation are free of recirculation in both normal volunteers and stroke patients.

## Materials and Methods

Perfusion images were acquired from three healthy volunteers (one male, two females, age 24-33) at a 3T scanner (Allegra, Siemens) and five acute stroke patients (three males, two females, age 63-83) at a 1.5T scanner (Vision, Siemens) using a single shot $T_2^*$-weighted EPI sequence. The imaging parameters were similar for both patients and volunteers with the exception of TR and TE (1.5s and 28 msec at 3T and 2s and 54 msec at 1.5T). The susceptibility related signal changes were first converted to concentration curves. Maximum likelihood ICA analysis (ISP group, DTU, http://isp.imm.dtu.dk/toolbox) was applied to concentration time curves for each 5×5 region of interest (ROI) as:

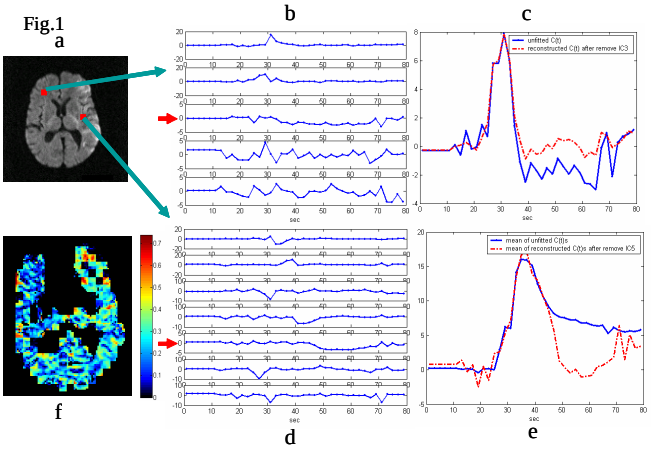
$$x_i(t_j) = \sum_{k=1}^{M} a_{ik} s_k(t_j) \quad (i = 1,\mathrm{L}\ ,25;\ j = 1,\mathrm{L}\ ,N) \quad (1)$$

where $x_i(t_j)$ is the concentration curve of voxel $i$ at $t_j$, $a_{ik}$ is the mixing coefficient, $s_k(t_j)$ is the $k$th independent component (IC) at $t_j$, $N$ is the number of measurement, and $M$ is the number of sources. $M$ was set to 5 first for each ROI assuming that the observed signal at any voxel is composed of arterial, venous, tissue, recirculation and noise sources (including cardiac, respiratory and white noise) contributions. ICs were ranked according to the relative energy $P_k$ ($k$ = 1, …, $M$) in a descending order.

$$P_k = \sum_{i=1}^{v} a_{ik}^2 \sum_{j=1}^{N} s_k^2(t_j) \Big/ \sum_{k=1}^{M} \sum_{i=1}^{v} a_{ik}^2 \sum_{j=1}^{N} s_k^2(t_j) \quad (k = 1,\mathrm{L}\ ,M) \quad (2)$$

ICs with a low relative energy and a late broad dip were identified as the recirculation components. If no recirculation associated IC was identified, $M$ was increased to 7 and ICA was repeated. After identifying the recirculation components, such components were excluded and concentration curves were reconstructed using the remaining ICs. In order to determine the effectiveness of the proposed approach for removing effects of recirculation, relative CBV (rrCBV) was computed for each voxel as the area underlying each concentration curve [3-4] with and without recirculation removal.

Fig.1




## Results

The proposed approach is highly effective and consistent for removing recirculation in normal volunteers (data not shown). In addition, a representative example from an acute stroke patient is shown in Fig. 1. A diffusion weighted image is shown in (a), delineating the presence and extent of the ischemic lesions. The red squares indicate the two 5×5 ROIs used for ICA: one in the contralateral and the other in the ipsilateral hemispheres with respect to the lesion. Five ICs are observed from the ROI in the contralateral hemisphere (b) and IC3 (marked by the red arrow) is identified as the recirculation component with a low relative energy of 2.99% and a late broad dip. The concentration curves before (blue) and after (red) the removal of the recirculation component are shown in (c). In contrast, 7 ICs are identified from the ROI in the ipsilateral hemisphere (d) and IC5 (marked by the red arrow) is identified as the recirculation component with a low relative energy of 8.85% and a late broad dip. It is immediately evident that the proposed approach substantially minimizes the contribution of recirculation while preserving the effects of first passage (e). The percent difference of rrCBV with and without removing recirculation is shown in (f). As anticipated, the largest differences locate within the ischemic lesion where the first passage and recirculation heavily overlap.

## Discussion

We have demonstrated that ICA is capable of removing effects of recirculation in both normal and, more importantly, the ischemic brain tissues while preserving the contributions of first passage. This approach is likely to have profound implications for the calculation of CBF and CBV, particularly in regions where a substantial overlap between first passage and recirculation is suspected such as the ischemic lesion. While our results are encouraging, we have observed an increased concentration at later time points (Fig. 1e), particularly in acute stroke patients. This observed late contribution of contrast agent may be caused by the pre-determined number of ICs to be 5 or 7. Nevertheless, this observed late arrival of contrast agent should not affect the subsequent calculation of CBV and CBF since it appears to be well separated with the first passage (Fig. 1e), making it straightforward to remove its effects. In addition, a Bayesian method was employed to estimate the number of sources (ISP group, DTU, http://isp.imm.dtu.dk/toolbox) from normal volunteers. We found that 5 or 7 components account for most signal variance. In conclusion, the ability to accurately remove effects of recirculation should further improve the accuracy of DSC for obtaining CBV and CBF.

## References

[1] Comon P., “Independent component analysis: a new concept?”, Signal Processing, 36, 287-314, 1994.

[2] Bell A. J., Sejnowski T. J., “An information-maximization approach to blind separation and blind deconvolution”, Neural Comput., 7, 1129-1159, 1995.

[3] Belliveau J. W., Rosen B.R., Kantor H.L. et al., “Functional cerebral imaging by susceptibility-contrast NMR”, Magn. Reson. Med., 14, 538-546, 1990.

[4] Axel L., “Cerebral blood flow determination by rapid-sequence computed tomography—a theoretical analysis”, Radiology, 137, 679-686, 1980.