Correcting Bolus Delay Confounds on Flow Estimations using Independent Component Analysis 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

With the dynamic susceptibility approaches, it has been recently suggested that bolus delay, particularly in patients with cerebral ischemia, will lead to inaccurate estimates of cerebral blood flow (CBF) using singular value decomposition deconvolution (SVD). Approaches to potentially correct this confound have been proposed by several investigators. Wu *et al.* propose to utilize a circular SVD (cSVD) approach which is less sensitive to bolus delay and thereby minimizes the inaccuracy [1]. In contrast, Calamante *et al.* propose to utilize an independent component approach (ICA) to determine the local arterial input functions (AIF) [2]. While positive results have been reported using these two approaches, cSVD requires high SNR while the local AIFs defined in [2] may not completely preserve the original characteristics of the AIF due to, potentially, the imperfection of ICA. In this study, we investigate an alterative approach where ICA is used to determine the arrival time of the local AIF. Subsequently, the arrival time of the global AIF obtained from the middle cerebral artery (MCA) is modified in accordance with the arrival time of the local AIF. Finally, the time shifted global AIF is used as the local AIF for each region throughout the entire brain. By doing so, the correct bolus arrival time while preserving the general characteristics of AIF can be used to obtain estimates of CBF through SVD. Results demonstrate that the corrected CBF maps are consistent with the final lesion in 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 an 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). Patients were imaged at three different time points: tp1, 3-6 hrs; tp2, 1 week; and tp3, 4 weeks after symptom onset. A global AIF $C_{ga}(t)$ was measured by averaging the susceptibility signal changes in the MCA and then fitted by a gamma variate function to remove recirculation effects. The susceptibility related signal changes were converted to concentration curves. Maximum likelihood ICA analysis (ISP group, DTU, http://isp.imm.dtu.dk/toolbox) was applied to the concentration time curves for each 5×5 region-of-interest (ROI) throughout the entire brain 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 kth independent component (IC) at t_j, N is the number of measurement, and M is the number of sources. M was set to either 5 or 7 and ICs were ranked according to the relative energy P_k (k = 1, …, M) in a descending order [3]:

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

Time delay, $\Delta\tau$, between the selected local AIF component and the global AIF was estimated such that the arrival time for a local AIF was defined as $C_{la}(t)=C_{ga}(t-\Delta\tau)$ (3). CBF and MTT were then computed based on SVD using $C_{la}(t)$ and $C_{ga}(t)$ as AIFs, respectively, for both normal subjects and stroke patients.

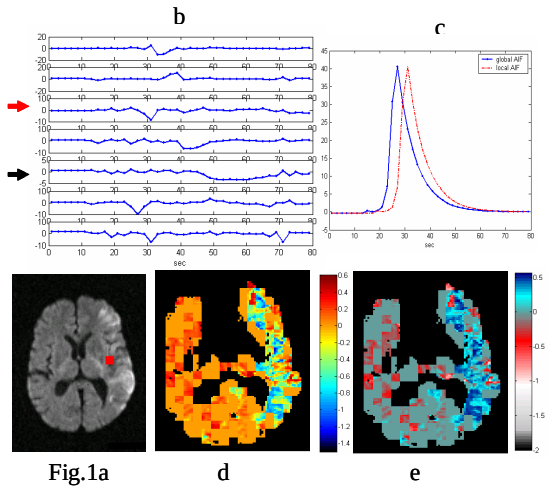

Fig.1a

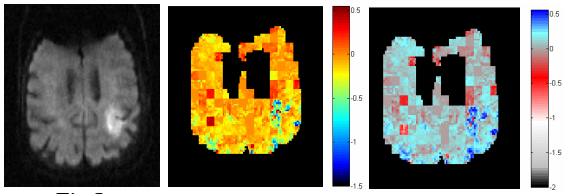

Fig.2 a

Results

A representative example from an acute stroke patient with a large ischemic lesion is shown in Fig. 1. A diffusion-weighted image (DWI) is shown in (a), delineating the presence and extent of the ischemic lesion. The red square indicates the 5×5 ROI used for ICA. Seven ICs are observed from this ROI (b) and the recirculation component, IC5 (marked by the black arrow), was removed first [3]. IC3 (marker by the red arrow) was chosen as the local AIF component and the $\Delta\tau$ was determined. $C_{ga}(t)$ (blue) and the time shifted global AIF which serves as the local AIF $C_{la}(t)$ (red) are shown in (c). The percent differences of the estimated CBF and MTT between using $C_{ga}(t)$ and $C_{la}(t)$ as AIF are shown in (d) and (e), respectively. As anticipated, the largest discrepancies with and without correcting for the delay of bolus arrival are observed in the ischemic lesion for both CBF and MTT. In addition, comparing the CBF maps at tp1 and the final T2 lesions obtained 30 days after symptom onset, our results suggest that the CBF maps obtained using the proposed approach yield a more consistent volume of infarction than that obtained without correction. In contrast, it is not surprising that our approach is less effective in normal volunteers (data not shown) as well as patients with a small ischemic lesion since $\Delta\tau$ is expected to be small. The DWI image and the percent difference of CBF and MTT computed using $C_{ga}(t)$ and $C_{la}(t)$ of an acute stroke patient with a small lesion are shown in Fig. 2 (a), (b) and (c), respectively.

Discussion

We have demonstrated that ICA is capable of identifying the local AIF, consistent with results reported by [2]. However, instead of using the local AIF identified by ICA for SVD as that proposed by [2], only the arrival time of the local AIF was employed in our study. Subsequently, the global AIF was time shifted for each region in the brain based on the ICA identified arrival time. By doing so, the general characteristics of AIF are preserved, which will be free from ICA induced errors, and the bolus delay is corrected. More importantly, the CBF maps obtained using the proposed approach yield a consistent lesion volume as that obtained in the T2-weighted images 30 days after symptom onset in stroke patients.

References

[1] Wu O., Østergaard L., et al., "Tracer arrival timing-insensitive technique for estimating flow in MR perfusion-weighed imaging using singular value decomposition with a block-circulant deconvolution matrix", Mag. Reson. Med., *50*, 164-174, 2003.

[2] Calamante F., Mørup M.., Hansen L. K., "Defining a local artarial input funciton for perfusion MRI using independent component analysis", Magn. Reson. Med., 52, 789-797, 2004.

[3] Y.Wu, H. An, H. Krim, W. Lin, "An Independent Component Analysis Approach for Removing Recirculation in Perfusion Weighted Images", submitted to ISMRM 2005, paper ID 828.