Use of White Matter as Reference Region to Quantify Dynamic-Susceptibility-Contrast MRI images

A. Bertoldo[1], F. Zanderigo[1], D. Peruzzo[1], and C. Cobelli[1]

[1]Department of Information Engineering, University of Padova, Padova, Italy

Introduction The quantification of Cerebral Blood Flow (CBF) from DSC-MRI images requires knowledge of the tissue contrast agent concentration, C(t), and the arterial input function AIF(t) to derive by deconvolution $R'(t)=CBF*R(t)$ from $C(t)=CBF\ [AIF(t)\otimes R(t)]$ where R(t) is the tissue residue function [1]. AIF can be found by manually inspecting tracer concentration maps (time consuming and operator dependent) or by using recently proposed fully or semi-fully automatic detection methods [2]. However, AIF correct measurement remains one of the most critical steps in DSC-MRI images quantification, i.e. it can be a major source of inaccuracy of CBF estimate and, consequently, of Cerebral blood Volume, CBV, and Meant Transit Times, MTT. To overcome these limitations, we present a mathematical approach for DSC-MRI quantification that does not require knowledge of AIF.

Material and Methods

The Reference Region Approach The rationale is to use a well-characterized region (reference region) to calibrate the signal intensity changes. The White Matter (WM) is proposed here as an internal reference for generating absolute MRI hemodynamic parametric maps since PET measurements show that in normal adult subjects, WM is characterized by a relatively uniform age-independent blood flow of 22 ml/100 ml/min [1]. Considering the concentration time curves in Gray Matter (GM): $C_{GM}(t)= CBF_{GM}\ [AIF(t)\otimes R_{GM}(t)]$ (eq.1), and for WM: $C_{WM}(t)= CBF_{WM}\ [AIF(t)\otimes R_{WM}(t)]$ (eq.2), one can show that $C_{GM}(t)=CBF_{GM}/CBF_{WM}\ [C_{WM}(t)\otimes R^*(t)]$ (eq.3) with $R^*(t)= R_{GM}(t)/R_{WM}(t)$. By deconvolution, using $C_{WM}(t)$ as an input, from eq.3 one obtains CBF_{GM}/CBF_{WM} from $R^*(0)$ and absolute CBF_{GM} by fixing CBF_{WM}=22 ml/100 ml/min. Absolute CBV_{GM} can also be obtained from $CBV_{GM}=CBV_{WM}\ \int C_{GM}(t)dt/\int C_{WM}(t)dt$ (eq.4) by assuming CBV_{WM}=2 ml/100g [3] and, finally one has, absolute MTT_{GM} from $MTT_{GM}=CBV_{GM}/CBF_{GM}$ (eq.5).

Clinical Data Set DSC-MRI data from 10 patients with severe atherosclerotic unilateral stenosis of internal carotid artery (MR equipment Signa Horizon CV 1.5 T GE Medical System, single shot EPI GE sequence, TE=51 ms, TR=1560 ms) were considered. For 6 subjects, DSC-MRI acquisition was repeated 6 months after surgery intervention to eliminate the stenosis. In total, 16 clinical cases were considered (i.e. 10 pre- and 6 post-surgery).

Parametric imaging In each subject, a Region Of Interest (ROI) has been manually drawn in the WM to obtain $C_{WM}(t)$. For sake of comparison, a global AIF has been automatically detected in each subject by hierarchical clustering applied dichotomously [2]. 64 CBF maps (16 x 4 slices in the central brain area) were generated as the maximum of the R*(t) functions obtained by Singular Value Decomposition (SVD) [1] using $C_{WM}(t)$ as an input and multiplying each values for 22 ml/100 ml/min. Corresponding 64 absolute CBV and MTT maps were then obtained. To compare the use of C_{WM} as input function vs AIF method, 64 CBF maps were also generated using SVD with AIF as input and multiplying each pixels to a common factor in order to obtain a value of 22 ml/100 ml/min in the WM ROI.

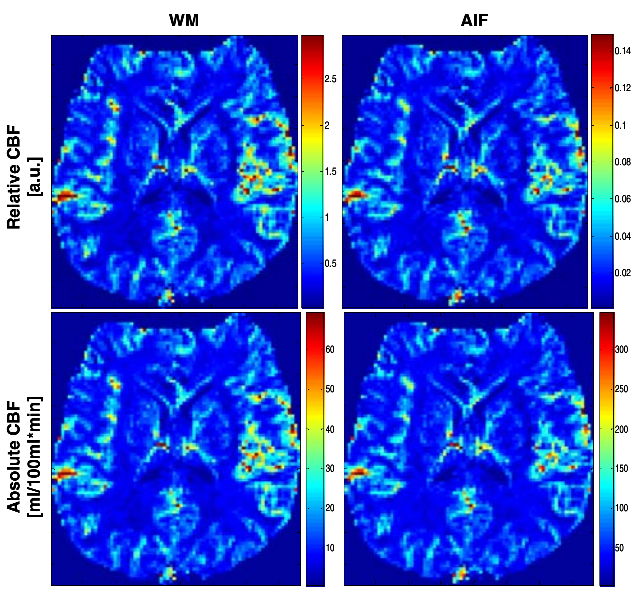

Figure 1

Results Relative CBF maps obtained in a representative subject by using C_{WM} (left) and AIF (right) as input of SVD are shown in Figure 1: both approaches provide the same relative flow distribution information. By considering CBF absolute values (Figure 1, lower panel), deconvolution with C_{WM} provides CBF values in the accepted range and comparable to PET values [4], while deconvolution with AIF provides unphysiologically high CBF values. This trend in CBF results is the same in the other 9 analyzed patients. Absolute CBV (Figure 2 – same representative subject of Figure 1) as well as MTT (not shown) estimated by the WM reference region approach are also in the pathophysiological range.

Discussion The use of a reference region as input function is a well consolidate method in quantification of Positron Emission Tomography images [5] and could represent an alternative approach to obtain quantitative assessment of cerebral hemodynamics from DSC-MRI, overcoming the need to measure an AIF devoid of partial volume and/or bolus dispersion. In particular, the use as input function of a reference region allows to minimize the problem of partial volume presence in AIF and to improve signal-to-noise ratio. In fact, the input signal can be obtained from a larger area in comparison to that usable for an accurate AIF measurement and averaging a larger number of voxel signals. Furthermore, the assumption of a relatively uniform age-independent blood flow in WM is not heavier than those behind the model commonly used to interpret DSC-MRI signal as, for instance, equal difference in hematocrit between capillaries and large vessels for all subjects both controls and patients [6]. However, in case of pathologies affecting WM or uncertainty about WM mean CBF and/or CBV values, only CBF_{GM}/CBF_{WM} and CBV_{GM}/CBV_{WM} ratios can be used. Finally, it is worth noting that an automatic detection of a reference region like WM could be easier in comparison with AIF extraction, especially if robust segmentation algorithms between GM and WM are considered.

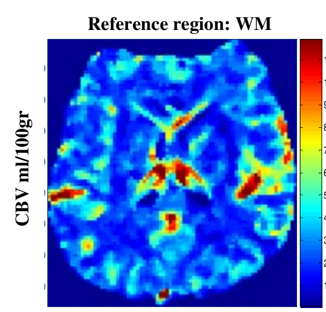

Figure 2

Acknowledgements The authors would like to thank Dr. Mirco Cosottini for making available the brain data set.

[1] Ostergaard et al., Magn Reson Med. 36: 715-725, 1996; [2] Peruzzo et al., 14th ISMRM Intern. Congr. & Exhibit., Seattle, Washington, USA, May 2006; [3] Perthen et al., Magn Reson Med. 47:61–67, 2002; [4] Markus et al., J. Neurol. Neurosurg. Psychiatry 69: 48-53, 2000; [5] Lammertsma et al., J. of Cereb. Blo. Fl. & Metab. 16: 42-52, 1995; [6] Calamante et al., J. of Cereb. Blo. Fl. & Metab. 19: 701-735, 1999.