Assessment on clinical data of nonlinear stochastic deconvolution versus SVD and block-circulant SVD methods for quantitative DSC-MRI

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Introduction. Dynamic Susceptibility Contrast – Magnetic Resonance Imaging (DSC-MRI) allows to quantify Cerebral Blood Flow (CBF), Volume (CBV) and Mean Transit Time (MTT) by measuring Arterial Input Function AIF(t) and tissue concentration C(t) and estimating by deconvolution the tissue Residue function R(t): $C(t) = CBF \cdot [AIF(t) \otimes R(t)]$ (eq.1). Singular Value Decomposition (SVD) [1] is currently the gold standard deconvolution method, but bears some limitations: nonphysiological oscillations and negative values in R(t), estimated CBF dependence on selected threshold, delay/dispersion in AIF [2]. To overcome SVD limitations, a block-Circulant matrix SVD (cSVD) [3] and Tikhonov regularization (TIKH) [4] have been proposed, although the latter has never been extensively applied to clinical data. In [5] we proposed a Nonlinear Stochastic Regularization (NSR) method able to account for smoothness and non-negativity of R(t) and dispersion of AIF. NSR [6] is a nonparametric Bayesian method which considers $CBF \cdot R(t) = d(t) \otimes CBF \cdot e^{R_1(t)}$ (eq.2), where $d(t) = 1/\theta_1 \exp(-t/\theta_1)$ (eq.3) stands for the dispersion and $R_1(t) = \alpha + \theta_2 \beta(t)$ (eq.4), with β(t) Brownian motion and θ_1, θ_2 and α unknown scalars, for the non dispersed component. On simulated data, NSR has been shown to perform best in comparison to SVD, cSVD and TIKH in estimating physiological R(t) in presence/absence of dispersion and in quantifying the level of dispersion [5,7]. Here SVD, cSVD and NSR are compared for the first time on clinical data.

Material and Methods.

Data. DSC-MRI data of 11 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, slices number x subject=12) are considered. For 8 subjects, DSC-MRI acquisition was repeated 6 months after carotid artery stenting to eliminate the stenosis. In total, 18 clinical cases are considered (i.e. 10 pre- and 8 post-stenting). In each subject, a global AIF is automatically detected by Hierarchical Clustering applied dichotomously [8]. **Map Generation.** CBV maps were calculated according to [9] after Gamma-variate fit to eliminate recirculation in C(t) and AIF(t). CBF maps were then generated as the maximum of the CBF•R(t) functions obtained by SVD, cSVD, NSR and corrected-for-dispersion NSR (cdNSR). Corresponding MTT maps were calculated as the ratio between CBV and CBF. In each slice, two large Regions Of Interest (ROI) containing both grey and white matter were manually drawn in normal (pathological) hemisphere. In each subject, mean CBF (MTT) values were calculated in the ROI and mean ratio between normal and pathological hemisphere (i.e. CBF_{norm}/CBF_{path} and MTT_{norm}/MTT_{path}) considered across the 12 slices to investigate the differences in CBF (MTT) detected by the methods. In the end, θ_1 maps by NSR were also evaluated.

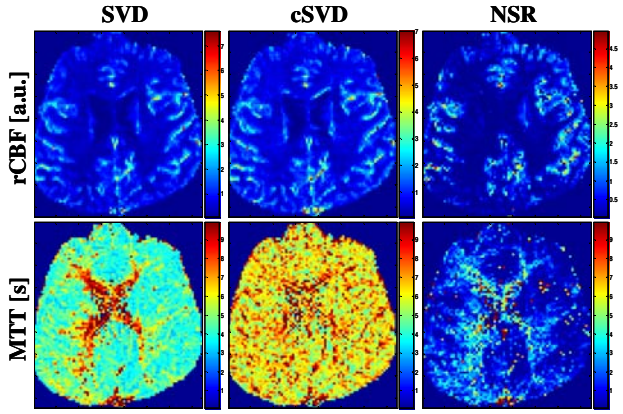

Figure 1: normalized relative CBF (absolute units) and absolute MTT (seconds) map obtained by SVD, cSVD and NSR in a representative subject in pre-stenting situation.

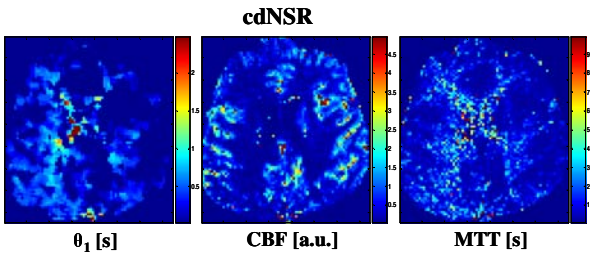

Figure 2: median filtered dispersion (seconds), normalized relative CBF (absolute units) and absolute MTT (seconds) map obtained by cdNSR in a representative subject in pre-stenting situation.

Results. In 70% of pre-stenting cases, NSR and cdNSR show normal to pathological CBF_{norm}/CBF_{path} ratios up to 70% higher than those by SVD and cSVD, providing a more evident identification of pathological hemisphere. cdNSR ratios are slightly lower than those by NSR, due to the recovery of underestimated CBF in presence of dispersion in the pathological hemisphere. SVD and cSVD CBF_{norm}/CBF_{path} ratios are often very close to one, thus making the identification of pathological areas more difficult. In those cases where MTT ratios agree with pre-stenting diagnosis, NSR and cdNSR show normal to pathological MTT_{norm}/MTT_{path} ratios up to 40% lower than those by SVD and cSVD. Otherwise, all the methods show ratios slightly higher than one, probably due to the behavior of MTT which is expected to be substantially constant across brain regions and significantly vary only in peripheral or heavily impaired areas. As expected, MTT_{norm}/MTT_{path} cdNSR ratios are slightly higher than those by NSR, due to the recovery of overestimated MTT in presence of dispersion in the pathological hemisphere. In post-stenting, all three methods generally show CBF_{norm}/CBF_{path} and MTT_{norm}/MTT_{path} ratios closer to one, suggesting the recovery of the stenosis.

Fig.1 shows CBF (MTT) map obtained by SVD, cSVD and NSR in a representative subject in pre-stenting situation: relative CBF are in absolute units and normalized to the same pixel in each map; absolute MTT are in seconds. Of note is that CBF (MTT) map obtained by NSR are comparable to those by SVD and cSVD but show more contrasted areas thus improving the detection of flow (transit time) differences. Fig.2 shows the dispersion (θ_1) map and the corresponding non dispersed CBF (MTT) map obtained by cdNSR. θ_1 has been shown to clearly identify cerebral areas with enhanced level of dispersion, thus providing information about the reliability of CBF (MTT) estimates in those areas, and to be highly correlated to CBF and MTT.

Discussion. CBF (MTT) maps obtained by NSR are comparable to those by SVD and cSVD, but show more contrasted areas thus improving the detection of flow (transit time) differences. cdNSR also provides dispersion and non-dispersed CBF maps. In particular, parameter θ_1 identifies cerebral areas with enhanced level of dispersion. This provides information on the reliability of CBF (MTT) estimates in those areas and candidates θ_1 as an indicator of pathological tissue state complementary to CBF, CBV and MTT. Of note is that θ_1 map can potentially provide physiological information less affected by cerebral auto-regulation and compensation mechanisms.

[1] Østergaard et al., MRM 36: 715-725, 1996 [2] Calamante et al., MRM 44: 466-473, 2000; [3] Wu et al., MRM 50: 164-174, 2003; [4] Calamante et al., MRM 50: 1237-1247, 2003; [5] Zanderigo et al., 13th ISMRM Intern. Congr. & Exhibit., Miami Beach, Florida, USA, May 2005; [6] Bell et al., Inv. Prob. 20: 627-646, 2004; [7] Zanderigo et al., 14th ISMRM Intern. Congr. & Exhibit., Seattle, Washington, USA, May 2006; [8] Peruzzo et al., 14th ISMRM Intern. Congr. & Exhibit., Seattle, Washington, USA, May 2006; [9] Rempp et al., Radiology 193: 637-641 (1994).