Effect of AIF distortion and delay on CBF estimation using FT based MMSE deconvolution technique

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Introduction

Ischemic stroke is one of the leading causes of mortality in the US. Quantifying CBF accurately may provide useful information about the disease progress and may be a useful marker for evaluating treatment efficacy. Bolus-tracking techniques, based on dynamic susceptibility contrast MRI using Gd-DTPA, have been widely used to quantify CBF. These techniques involve deconvolution of time-concentration curve by an estimated AIF, using SVD, FT or minimization/regularization methods. A common challenge for these techniques is accurate estimation of the AIF, especially the location (delay) and the width [1-4]. SVD-based techniques, which are commonly-used, involve determining the best singular value threshold [2]. An optimal analytical determination of this threshold is still an open problem; it is usually determined via empirical look-up tables [4]. Fourier-transform-based techniques utilize the signal and noise separation in the frequency domain. In this study, a frequency-domain-based MMSE technique has been proposed that optimally estimates CBF. The main aim of this simulation study was to investigate the effect of AIF distortion and delay on the proposed technique and compare the results with the SVD technique.

Materials and Methods

Simulation experiments were performed using MATLAB (7.2.0 R2006a, Mathworks, Natick, MA). The MMSE-based technique was applied to simulated data for a set of CBF values in the range of 5 - 80 ml/100g/min. A simulated exponential residue function, r(t), with time parameter of 2 seconds and scaled with these CBF values, was convolved with a simulated Γ-weighted AIF function, $a(t)=\alpha(t-t_0)\exp\{-\beta(t-t_0)\}$, where $\alpha=0.082$, $\beta=0.286$, $t_0=20.5$ sec., $t_{max}=25$ sec. The functions were sampled at 50 time-points with separation, $T_R=1.6$ sec. The resulting concentration curve, c(t), was then converted into simulated gradient-echo EPI signal, s(t), by using the relation $s(t)=s_0\exp\{-kT_E c(t)\}$, where, baseline signal $s_0=400$, coefficient k=0.4, and echo-time $T_E=78$ msec. This corresponds to an EPI signal with 48% baseline-drop for CBF=80 ml/100g/min. Then, zero-mean Gaussian noise, n(t), with certain standard deviation (6.4) was added to obtain noisy signal, $s_n(t)$. The noisy concentration signal, $c_n(t)$, was then calculated based on the inverse relation $c_n(t)= -1/(kT_E)\log(s(t)/s_0)$. Perfect AIF-fit was realized by using the original AIF in the deconvolution. Φ(f) that would lead to MMSE residue function was derived analytically and computed, based on the Fourier-transforms $C_n(f)$, A(f), and the noise std. Then, the residue function and the CBF were computed by taking the inverse Fourier-transform of the ratio $\Phi(f)C_n(f)/A(f)$. AIF functions that have twice and half of the full-width at half-maximum of the original AIF were simulated (with the area under AIF kept constant) for the deconvolution in the study of the width-effect, and, an AIF that has 3.2 seconds delay with respect to the original AIF ($t_0=23.7$, $t_{max}=28.3$) was simulated for the study of the delay-effect. 100 realizations were run and average results and their standard deviations were calculated.

Results and Discussion

Figure 1 presents the effect of accuracy of width and delay in estimating AIF on CBF estimation for the MMSE-based technique ((a)-(d)) and the SVD-based technique ((e)-(h)). As a benchmark, the results in case of perfect estimation of AIF are presented in (a) and (e). Plots in (b) and (f) compare the two techniques when the AIF is estimated to be twice narrower than it actually is; (c) and (g) compare them when the AIF is estimated to be twice wider; (d) and (h) compare them when the AIF is estimated to be 3.2 seconds delayed. SVD-based results were obtained by picking the first 20 singular values. Φ(f) values that are non-zero for $f>f_{max}/2$ were set to zero since these correspond to noise effects that arise from under-sampling. MMSE-based technique is more sensitive than the SVD-based technique when the width of the AIF is under- or over-estimated. It is insensitive to the error in estimating the delay of the AIF, whereas SVD-based technique suffers from the delay. The insensitivity stems from the nature of the FT, since the delay in a(t), and hence c(t), manifest itself as a multiplying factor in the A(f) and C(f). Future work involves using the information obtained from Φ(f) to improve the stability of the FT-based MMSE technique and apply the proposed technique to human MRI data.

References: [1] Wirestam R. *et al.*, *MRM*, 13: 691-700 (2000) [2] Østergaard L. *et al.*, *MRM*, 36: 715-725 (1996) [3] Østergaard L. *et al.*, *MRM*, 36: 726-736 (1996) [4] Calamante F. *et al.*, *MRM*, 44: 466-473 (2000) [5] Liu H.-L. *et al.*, *MRM*, 42: 167-172 (1999).

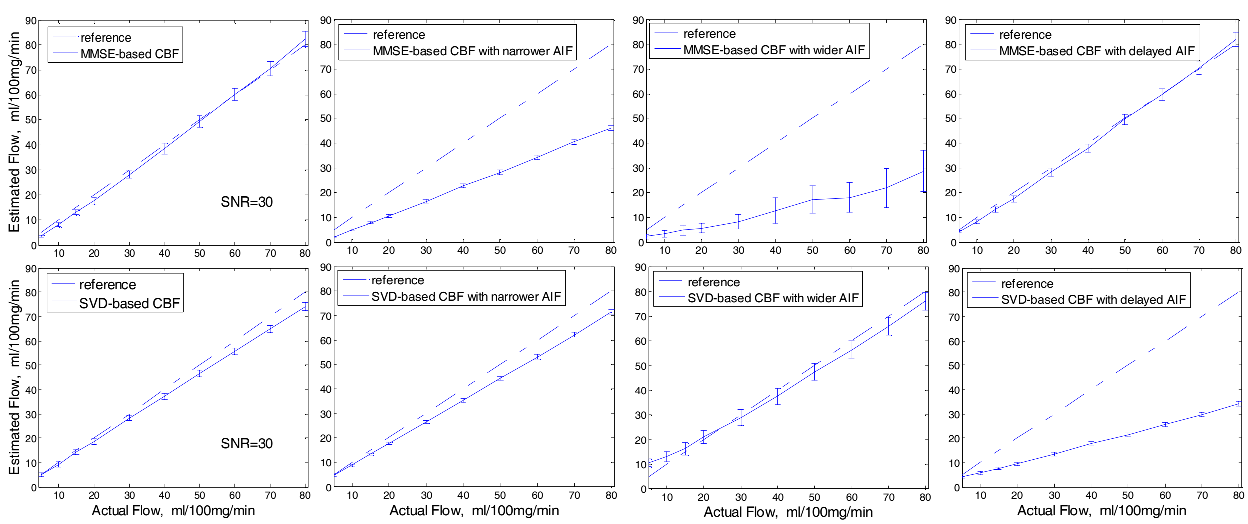

Fig. 1 Effect of accuracy of width and delay in estimating AIF on CBF estimation. (a)-(d): MMSE-based CBF estimation.(e)-(f): SVD-based CBF estimation.