Dynamic susceptibility Contrast MRI: Compromising Perfusion Accuracy for a Better Discrimination of Hypoperfused Tissue

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Introduction

In dynamic susceptibility contrast MRI perfusion weighted imaging (PWI), the precision (random error due to noise) and accuracy (systematic bias) of derived perfusion values rely critically on the noise regularization used in the deconvolution process. The regularization parameters used in common deconvolution methods are optimized for the best reproducibility of 'true' perfusion values across a range of physiologically realistic perfusion parameters based on a single, standardized arterial input function (AIF) shape [1-4]. Here we show that this accuracy is obtained at the expense of precision, which negatively impacts the ability to identify critical hypoperfusion thresholds. We then present a framework for frequency-domain optimized regularization. This alternative approach implies application of low pass filters to the spectrum of the residue function, R(ω), applicable to deconvolution methods based on Fourier transform (FT) and block-circulant singular value decomposition (SVD). This approach reveals that optimal regularization depends critically not only on signal to noise ratio (SNR), but also sampling rate (TR) and AIF shape. We produced a look-up table of the optimal regularization parameter, the filter cut-off frequency, ω_{opt}, across a range of AIF widths (σ_{AIF}), SNRs and TRs. Application of ω_{opt} to simulated data yield a better discrimination of hypoperfused tissue.

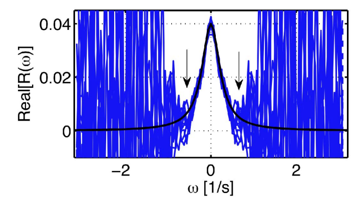

Figure 1: Deconvolution in Fourier domain. 10 noise realizations for TR=1s and SNR=40 super-imposed on the true spectrum of the residue function.

Methods

We performed perfusion simulations (described in [2] and more details can be found in [5]) varying σ_{AIF}, SNR and TR. Deconvolution was done in Fourier domain using $c_t(\omega)/c_a(\omega)$, where c_t and c_a are the spectra of tissue and AIF, respectively. We operationally defined ω_{opt} as the frequency above which R(ω) was dominated by noise (arrows in fig. 1). The optimal cut-off was found as the minimum of the error curve defined as, E(ω)=mean(R(ω))+std(R(ω), where R(ω) is the Lorentzian shaped spectrum of an exponential residue function. We used a 5 point smoothing filter before minimizing E(ω).

Results

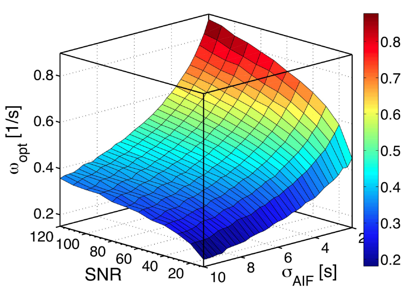

Figure 2: Cross section of the ω_{opt}-look up table with parameters TR = 1s and MTT = 6s.

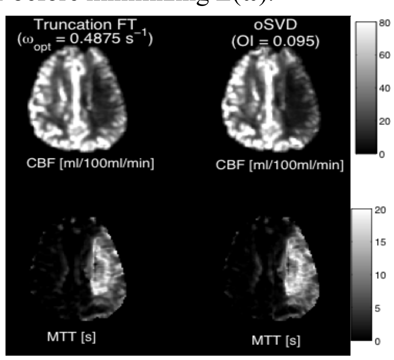

Figure 3. Acute PWI of a 70 year old woman with occlusion at MCA-m2. PWI protocol: 3.0T scanner (GE), GRE (TR/TE = 1.5s/45ms). The images are normalized to white matter and spatial smoothed with a kernel of 3 voxels.

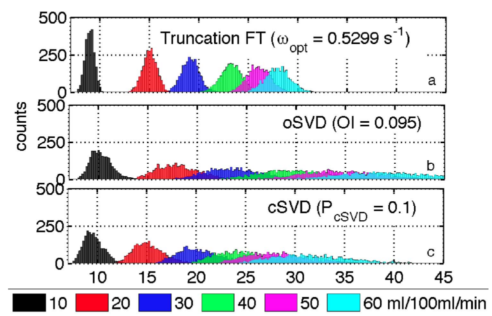

Figure 4. Distributions of CBF obtained with three deconvolution methods for 2500 noise realizations and different true CBF levels. CBV = 0.04, TR = 1.5s, SNR = 40 and AIF is mean of five noise realizations. Improved discrimination of low CBF is evident in (a).

We find that ω_{opt} depends critically on SNR and σ_{AIF} (fig. 2). The strong dependence on the AIF for the regularization parameter have not been taken into account in previous studies, however the tendency of more accurate CBF estimates as the AIF narrows were observed in several other studies such as [6-8]. Moreover, we find that despite the narrower dynamic range of CBFs and MTTs (due to the reduced accuracy – fig. 4a compared to fig. 4b-c), the proposed method demonstrates tissue contrast comparable to the known methods (fig. 3). We present an increased ability to discriminate between hypoperfusion levels (fig. 4).

Discussion & Conclusion

The main result of this study is a markedly improved discrimination of CBF (fig. 4a) as compared to the estimates using the widely used regularization levels in [2]. The new regularization approach leads to lower accuracy of CBF estimates but markedly increases precision (fig. 4). The use of the new regularization level may therefore improve the differentiation of subtle CBF or MTT differences proposed to distinguish salvageable tissue from tissue prone for infarction in stroke patients as compared to currently used regularization levels.

References: [1] Østergaard et al, MRM 36:715-725 1996 [2] Wu et al, MRM 50:164-174 2003 [3] Liu et al, MRM 42:167-172 (1999) [4] Carpenter et al, MRM 55:1342-1349 (2006) [5] Kjølby et al. Manuscript submitted to NeuroImage, [6] Knutsson et al., MRI 22:789-798 2004 [6] van Osch et al., MRM 50:614-622 2003 [8] Straka et al., Proc. ISMRM, p. 1898 (2008)