Use of Adaptive Deconvolution Algorithms Reveals New Variation of Cerebral Blood Flow Estimates with Arterial-Tissue-Delay in Dynamic Susceptibility Contrast MR Perfusion Studies

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Introduction

It has been long reported[1,2] that quantitative cerebral blood flow (CBF) estimates obtained from dynamic susceptibility contrast (DSC) MR perfusion studies vary with the arterial-tissue-delay (ATD). Recently Smith *et al.*[3], and Wu *et al.*[4], have shown that this variation is an artifact generated when applying the standard singular value decomposition (sSVD) algorithm under inappropriate circumstances. Correct SVD algorithm implementation[3,4] [*e.g.* using the reformulated SVD (rSVD) algorithm[3]] for the experimental conditions that arise in DSC studies produces CBF estimates that are effectively independent of ATD but systematically under-estimated. Fourier transform (FT-based) deconvolution provides equivalent underestimated CBF values.[3] This underestimation is a direct consequence of the need to employ noise filters to ensure deconvolution stability. It has been suggested that adaptive noise removal approaches[5] be used to partially compensate for this under estimation. In this paper, we show that the use of adaptive deconvolution approaches reveals a new, previously unrecognized, variation of CBF estimates as a function of ATD because of the experimental under sampling (aliasing) of tissue signals with current DSC perfusion protocols.

Method

A series of arterial $c_a(t)$ and tissue, $c_{VOI}(t)$, signals were analytically generated based on a single compartment (exponential) residue function.[1] Sampled values of the signals were determined at times $t = n\Delta T_{EXPT}\ ; 0 \le n < N$ where ΔT_{EXPT} = 1 s and 2 s is the time interval between the time sequence of DSC images. The residue function estimates were recovered using the time-domain sSVD[1] and rSVD[3] algorithms and the frequency-domain FT-based deconvolution algorithms.[1] To simulate using an adaptive singular value decomposition algorithm in the presence of changing noise levels, the singular values threshold parameter (P_{SVD}) was set to 0.2 (high noise environment) and 0.001 (low noise environment). Arterial tissue delay were simulated from –2 s to +4 s at intervals of 0.25 s.

Results

Deconvolution in high-noise environments requires that P_{SVD} = 0.2, *i.e.* many singular values are discarded. For the sSVD algorithm, this resulted in CBF estimates that varied rapidly with ATD for ATD < 0 s, and to a minor extent for ATD > 0 s (see Fig.). The rSVD and low-pass filtered FT (LP-FT) results showed an equivalent, minor variation of CBF with ATD. The variation of CBF with the size of the sampling interval ΔT_{EXPT} was also small (not shown). The average underestimation of CBF was reduced when the SVD threshold P_{SVD} was reduced, *i.e.* a lower noise environment permitting the retention of more singular values. However larger changes were seen in the CBF estimates both as function of ATD and as a function of ΔT_{EXPT}. It can be seen that decreasing the sampling interval (increasing the sample rate) reduced the variation of the CBF estimates as a function of ATD.

Conclusion

Using a singular-value threshold, or a FT low-pass-noise filter, reduces the noise present on the concentration signals, leading to improved algorithmic stability. Unfortunately, CBF under-estimation results as high-frequency signal components are also removed. An adaptive noise threshold permits retention of more signal components and should, in principle, provide improved CBF estimates. However, current DSC protocols under-sample parts of the tissue signal that rapidly change, resulting in high-frequency signal distortion (aliasing) that depends on the relative positions of the arterial and tissue curves. Decreasing the noise filtering reveals this distortion. Smaller experimental sample intervals lead to more accurate high-frequency components of the tissue signals, and the spectral components of the residue function, and improved CBF estimates when using adaptive algorithms. Frequency-domain modeling approaches[6,7] promise reduction of CBF dependence on ATD when experimental conditions do not permit smaller sampling intervals.

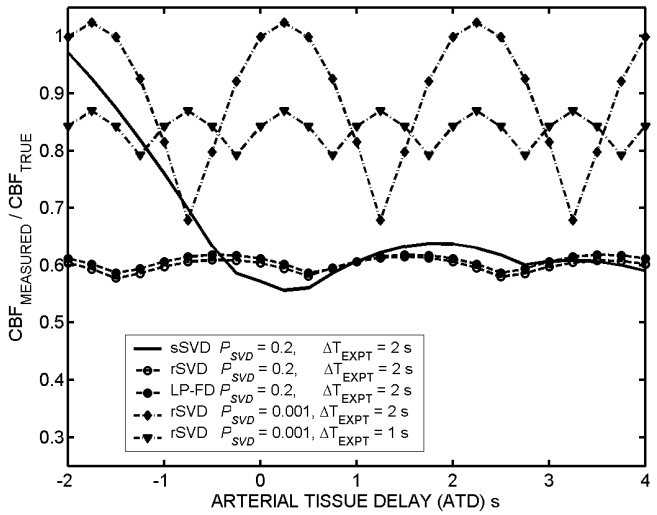

Fig. The CBF estimates depend on which deconvolution algorithm is used, the level of adaptive noise thresholding applied and the experimental sample interval's size.

References

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