A NOVEL APPROACH TO REMOVE THE EFFECT OF RECIRCULATION IN ARTERIAL INPUT FUNCTIONS

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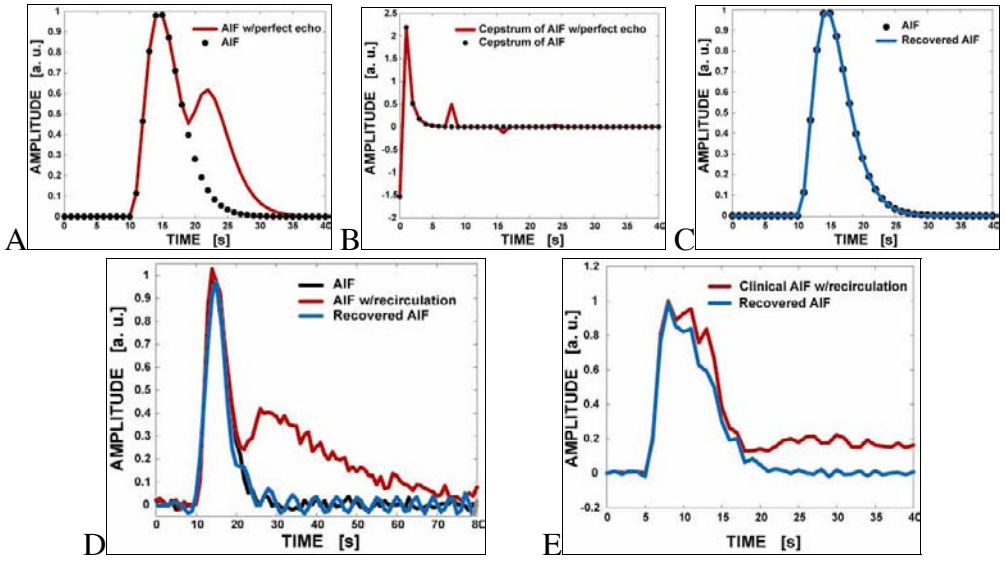
INTRODUCTION: Recently Gruner *et al.*[1, 2] have proposed using the cepstrum algorithm as an alternative approach to the more traditional SVD and Fourier transform deconvolution techniques used when estimating cerebral blood flow (CBF) in dynamic susceptibility contrast studies. Cepstrum offers some unique advantages; in particular the fact that the tissue concentration in the cepstrum domain is formed through an addition operation on the arterial signal and the residue function; rather than the time-domain convolution associated with SVD or the frequency domain multiplication of the Fourier techniques. In [2], Gruner *et al.* found it was necessary to extend the two-compartment contrast leakage model followed by repeated Picard iterations in order to isolate the first pass of contrast in the concentration function from the recirculation bolus prior to application of the cepstrum. In this paper, we wish to demonstrate how the recirculation bolus can be directly removed in a non-model specific manner during the cepstrum's application using an approach that is reminiscent of the original use of cepstrum in seismic analysis to locate the position of earth quakes. In this model, the recirculation bolus is treated as "an echo" of the arterial input function (AIF) leading to spikes in the cepstrum that can then be removed by filtering (liftering in cepstrum terminology), before reconstruction of the true AIF is performed using the inverse cepstrum.

METHOD: Three AIFs with recirculation were analysed. In the simulation study, the arterial input function (AIF), a gamma-variate function, was analytically generated as per [3] for the simulation study (1) with the recirculation bolus as an ideal, exact copy of the AIF (Fig. A) delayed by 8 s; (2) with noise added and the recirculation bolus as a broadened, delayed version of the AIF (Fig. D) [4]; (3) an actual clinical AIF with recirculation (Fig. E). The cepstrum of each arterial function was determined as follows: **Step 1:** First the z-transform was calculated i.e. $H_{AIF}(Z) = \sum AIF[nTR](z/TR)^{-n}$. This theoretical z-transform expression differs from that given in [1-2] by taking into account the fact that the actual image sequencing interval (TR) is typically in the range of 1 s to 2.25 s where as the z-transform is based on a normalized sampling interval (1 s). The z-transformation was achieved using the discrete Fourier transform; **Step 2:** After phase-unwrapping, the relative differences between the z-transform coefficients were flattened (whitening the spectrum) by calculating the logarithm of each spectral component. High frequency phase and amplitude filtering were then applied to reduce the noise present in the log signal *(c.f.* [1, 2]); **Step 3:** The cepstrum was then calculated by performing the inverse discrete Fourier transform; **Step 4:** In this preliminary study, the bolus echos were identified manually and removed before reconstruction using the inverse cepstrum.

RESULTS: In the ideal case (A), with the bolus treated as an exact delayed copy of the AIF, the expected echo peaks in the cepstrum (quefency signal) are clearly seen at 8 s intervals corresponding to the 8 sec bolus delay (B). Such isolated peaks are easy to lifter (filter), leading to an excellent estimate of the AIF without the recirculation bolus (C). The more physiologically-relevant broad and noisy circulation bolus (D) led to less obvious cepstral echoes, but still permitted good AIF recovery. After estimating the bolus delay, the AIF was recovered from a clinical signal (E).



(A) Arterial function combined with a perfect recirculation, bolus echo, (B) the corresponding cepstrum with the bolus expressed as "echos" added to the AIF cepstrum. (C) The recovered arterial signal after "echo removal". (D) Arterial function recovered from a noisy, more physiologically realistic, recirculation bolus. (E) Arterial functions recovered a clinical AIF in the presence of recirculation bolus with an estimated 10 s delay.

CONCLUSION: In this preliminary study, we have demonstrated a novel way of using the cepstrum which, in principle, allows the recirculation bolus to be removed from the AIF in a model-independent way. We have also corrected the original cestrum analysis theory [1, 2] to account for the MR perfusion imaging interval *TR*. Our long term goal is to remove the recirculation bolus using cepstral techniques prior to using distribution of transit time technique proposed by Salluzzi *et al*. [5] to overcome limitations of the SVD and Fourier deconvolution techniques. However, further investigation is necessary to identify an appropriate automated band-pass liftering (filters in cepstrum domain) to remove the bolus "cepstral echoes" and the effect of noise on the concentration signals.

REFERENCES: [1] Gruner *et al.,* MRM 2006, 55: 805-15 [2] Gruner *et al.,* JMRI 2006, 23: 273-284 [3] Østergaard L *et al*., MRM 1996; 36: 726-736. [4] Chen JJ *et al*., Phys. Med. Bio. 2005; 50: 1251-1263 [5] Salluzzi M *et al.*, Proc 14th ISMRM 2006: 2680.