Blind deconvolution of Brain Perfusion Images using Complex Cepstrum

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Magnetic Resonance Perfusion Imaging is a valuable diagnostic tool for identifying pathophysiological changes in the human brain [1]. The contrast concentration functions obtained in an imaging session reflect the perfusion of the capillary network of the brain (the tissue residue function), but are also influenced by the amount and type of contrast agent, the contrast injection speed and the wash-out velocity of the human blood transport system from the injected vein. Quantitative perfusion values require the removal of these latter components by deconvolving each image voxel with an arterial input function. Here, arterial input functions are estimated blindly on a voxel-by-voxel basis by transforming the convolved contrast concentrations to the complex cepstrum representation [3]. The estimated voxel specific arterial input functions are used in the subsequent deconvolution step, replacing the tedious and highly user dependent approach of identifying the contrast function in a brain feeding artery.

MATERIALS AND METHODS

Acquisition:

Patent data were acquired using vendor provided gradient-echo echo-planar imaging (Siemens Vision 1.5T, TR/TE=1442/60.82 ms, FoV=230 mm, Matrix =128x128, Time point measurements = 50). Results in one adult (female, 26 y) suffering from right-sided fiberous dysplasia were used for illustrating the proposed method. Evidence of collateral circulation was identified, implying in abnormal blood supply in the affected brain region.

Analysis:

The contrast concentration functions of time, $c_i(t)$, obtained in each voxel i, represent a convolution between an arterial input function, $v_i(t)$, and a tissue residue function scaled by blood flow (F), $u_i(t)=F\, r_i(t)$; $c_i(t) = v_i(t) * u_i(t)$. These convolved concentration functions are transformed to the complex cepstrum representation by z - transforms, $C(z = e^{j\omega}) = \Im\{ c_i(t)\} = \Im\{u_i(t)\}\, \Im\{v_i(t)\} = U(z)\, V(z)$. Applying a complex logarithm, and subsequently inverse z-transforming gives the complex cepstrum representation, $c_i(t) = v_i(t) + \hat{u}_i(t)$. With an appropriate cepstrum lifter (filter in cepstrum domain), $c_i(t) = v_i(t)$ is computed. Applying inverse homomorphic transformation to the cepstrum data, now gives the voxel specific arterial input functions. The subsequent deconvolution (nonparametric FFT) and estimation of hemodynamic parameters is performed as before [2].

The cepstrum representation of tissue residue functions that are exponential or linear in shape in time domain (as in e.g. [2]), are minimum phase sequences. Apart from the first time bin, their cepstrum representation is independent on flow and only dependent on mean transit time. Simulated gamma variate functions, representative of arterial input functions, however, exhibit maximum phase components for particular parameter choices. Based on these observations, a cepstrum lifter was restricted to only influence the minimum phase time bins in the complex cepstrum. Any maximum phase components were incorporated in the arterial input function estimation. In this study, the lifter was defined as a complex cepstrum representation of an exponential function with various decay rates. If the decay rate is chosen too small, an oscillating and partly negative arterial input function is restored by the homomorphic transformation. If the decay rate is chosen too large, the arterial input function is a simple decaying function – also non-realistic. Thus, the smallest decay rate that restores a positive arterial input function in time domain was used in this study.

RESULTS

In areas of collateral circulation, the arterial input function is more dispersed (lower/darker peak values a) and the peak more delayed (bright values in b). When deconvolving with an arterial input function estimated in each image voxel, mean transit times are comparable (slightly larger) with those obtained in normal tissue. Similarly, flow values were larger in this area when using voxel specific estimates than those obtained with the standard method.

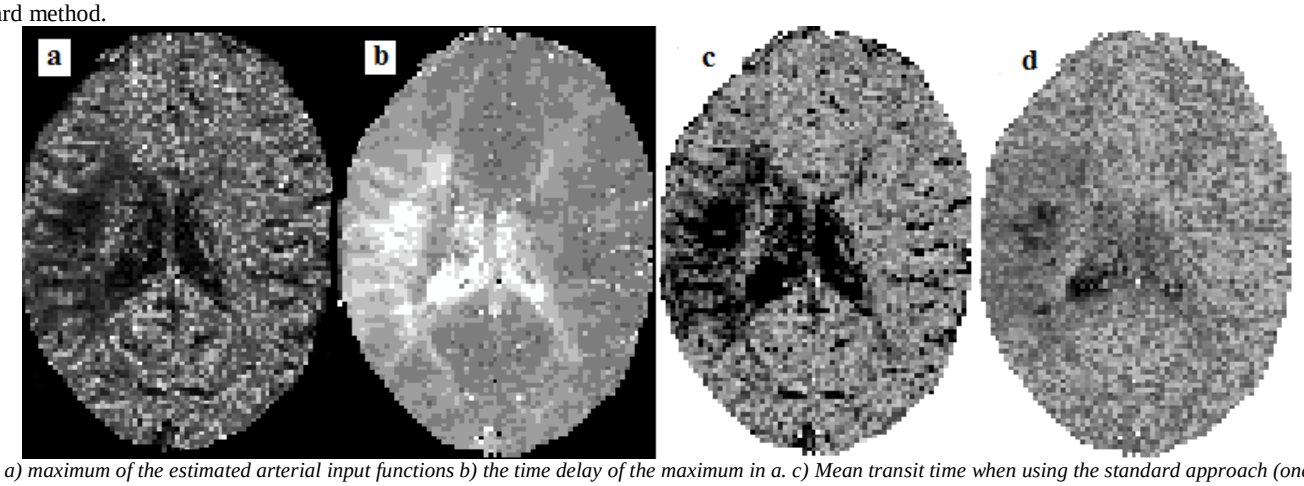

Figure a) maximum of the estimated arterial input functions b) the time delay of the maximum in a. c) Mean transit time when using the standard approach (one manually selected arterial input function for all voxels) d) Mean transit time when using blind deconvolution and complex cepstrum.

DISCUSSION/CONCLUSION

The convolution problem in perfusion imaging is addressed by transforming the convolved contrast concentrations to the complex cepstrum representation where a different relation exists between the arterial input function and the tissue residue function. Results show estimation of different arterial input function in different regions in the brain, and hemodynamic maps less biased by contrast delay and dispersion.

REFERENCES

[1]Rempp KA, et al.Radiology 1994;193:637-641 [2] Ostergaard L, et al. Magn Reson Med 1996;36:715-725 [3] Oppenheim AV, Schafer RW. Prentice-Hall Inc. 1989