On the Optimal Injection Speed for Bolus Tracking Perfusion

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Introduction

Quantitative perfusion MRI using bolus tracking is used to measure the cerebral blood volume (CBV) and flow (CBF) and the mean transit time (MTT). Those parameters are particularly important in acute ischemic stroke for identification of ischemic, yet salvageable tissue. For the evaluation of the measurements, the first bolus passage of an injected contrast agent trough the voxels is analyzed. The duration of this passage can be influenced by the injection speed and dose. In order to achieve sharp bolus profiles and therefore a high contrast to noise ratio (CNR) in the concentration curves, generally a high injection speed is preferable. As the contrast agent is administered in the arm vein, the bolus has to traverse the heart-lung system. Van Osch et al showed by simulations [1], that this limits the injection speed for Gd-DTPA based contrast agents to approximately 5ml/s. However, beside the CNR limitation, the temporal sampling of the involved functions influences the results as well and is set by the repetition time (TR) of the commonly used EPI sequences. Especially for the arterial input function (AIF) that has a sharp bolus profile by definition, a TR of approximately 1.5 seconds leads to aliasing effects that blur the CBF values. In order to set up a proper measurement protocol despite the above findings, the injection speed and dose are analyzed theoretically and experimentally using data from 16 volunteers.

Methods

DSC perfusion evaluation. The tracer kinetic is described by $c_t(t)=CBF*R(t)\otimes c_{aif}(t)$, where c_{aif} is the AIF, R(t) the residue function, CBF the cerebral blood flow and c_t the tissue concentration. In order to exclude recirculation effects the first bolus passage is extracted [2] from c_t and c_{aif}. The c_{aif} is found automatically using the algorithm proposed in [3]. The deconvolution is performed using the Fourier convolution theorem. For numerical stability during the deconvolution spectra of R are set to zero for denominators smaller than 10^{-8}. CBF can be found by integrating the spectrum of R.

Simulation. In order to illustrate the effect of undersampling, densely sampled tissue and arterial first bolus passage concentration curves are generated using gamma variate functions with appropriate [4] parameters. Those curves are then sampled at a rate (1.8s in Fig. 1) as typically used in DSC perfusion measurements.

Data acqusition. All measurements where performed on a 3T TIM Trio (Siemens, Germany) using a multiecho (GE/SE) EPI sequence with TR = 1800, TE_{GE} = 25, TE_{SE} = 85, FOV 240mm x 240mm x 80mm, matrix size 72x72 at 16 slices. 50 time points were acquired during the bolus passage for each voxel. The study was approved by the local ethics committee. 16 young and healthy volunteers underwent the protocol at varying injection rates and applying different contrast agent (Multihance) dosages (2 volunteers: 2ml/s@1dose, 4 volunteers: 3ml/s@1dose, 2 volunteers: 3ml/s@1.5dose, 2 volunteers: 3ml/s@2dose, 2 volunteers 4ml/s@1dose, 2 volunteers: 5ml/s@1dose, 2 volunteers 5ml/s@1.5dose).

Results

The simulation shows that aliasing is present in typical perfusion data even in absence of noise. The point where aliasing significantly changes the spectrum of R even when noise is absent (Fig. 1), is found be approximately $\omega = \pi/(2*TR)$ (green bars in Fig. 1 and Fig. 2). Strength and direction of the undersampling effect vary strongly with the realization of a noisy AIF. The introduction of white Gaussian noise shifts this threshold towards smaller frequencies (Fig. 2).

The spectra of R were determined for every dataset. The complex spectra where averaged over all pixels that had a baseline SNR larger than 50. The mean spectra are shown in Fig. 3 for injection times smaller or equal than 3*TR and in Fig. 4 for larger than 3*TR.

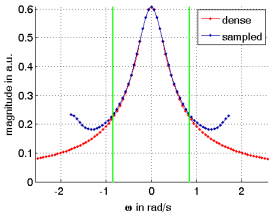

Fig. 1: Simulated spectrum of R. Aliasing of the sampled curve.

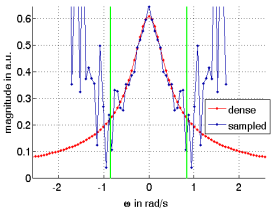

Fig. 2: Simulated spectrum of R. Effect of noise upon aliasing.

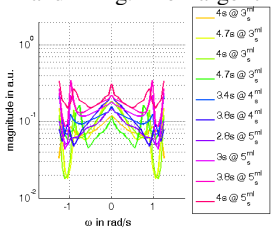

Fig. 3: Measured spectrum of R. All volunteers with $t_{inj} \leq 3*TR$.

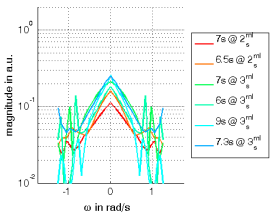

Fig. 3: Measured spectrum of R. All volunteers with $t_{inj} > 3*TR$.

Discussion

The R spectra are similar if injection duration is longer than 3*TR. If the peak concentration yields enough CNR the injection speed can be reduced in order to avoid aliasing. The quality of CBF estimates depends on the duration of the injection as well as on the peak concentration in the tissue. The optimization of those competing effects is conditioned by the amount of contrast agent that can be administered to the patient. As a consequence light patients have to receive a higher dosage than heavy ones at fixed injection speed.

When aliasing is minimized, the spectra show a low minimum, where a unique frequency can be defined by a minimum search. This frequency can be used for CBF correction by extrapolation if a proper model function (e.g. gamma variate) is chosen for c_{aif}, c_t (respectively R).

Refenrences

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[3] Carroll: Radiology 227 (2003)
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Acknowledgement:

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