Perfusion information obtained by dynamic contrast-enhanced phase-shift MRI: Comparison with model-free ASL

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Introduction

The relationship between the phase of the MRI signal and the concentration of contrast agent enables registration of arterial input functions (AIFs) in bolus-tracking perfusion MRI, with potential advantages such as favourable SNR and good linearity with concentration [1]. Already in 1992, the phase shift in tissue as a function of time after a bolus injection of contrast agent was investigated by Conturo et al. (without registration of AIFs) [2]. However, this approach never found widespread use, most likely due to the complicated dependence of the phase shift on vessel geometry. In the present study, phase-shift curves were registered in regions representing tissue as well as artery, and a phase-based cerebral blood flow (CBF) index was calculated and compared with corresponding quantitative CBF values obtained by model-free arterial spin labeling (ASL) [3].

Material and Methods

Fourteen subjects (9 females and 5 males, age 41-80 years) were investigated using 3T MRI (Philips Achieva). A contrast-agent dose of 0.1 mmol/kg b.w. was administered and phase images were collected during the first passage of the contrast-agent bolus. Images were acquired using a GRE-EPI pulse sequence with temporal resolution 1360 ms, echo time (TE) 29 ms, flip angle 90° and matrix size 128×128. The phase shift $\Delta\Phi$ in a voxel is proportional to the concentration C of contrast agent, i.e. $\Delta\Phi \propto TE \cdot F_{vasc} \cdot C$ [2]. The phase shift depends on the geometry and orientation of the vessels with respect to the main magnetic field and this is accounted for by the factor F_{vasc}. Concentration-dependent phase-shift images $\Delta\Phi_t$ were obtained by pairwise subtraction and subsequent summation according to $\Delta\Phi_t = \Delta\Phi_{2-1} + \Delta\Phi_{3-2} + \ldots\ldots + \Delta\Phi_{t-(t-1)}$, where $\Delta\Phi_{i-(i-1)} = \Phi_i - \Phi_{i-1}$. Phase-shift curves representing a brain-feeding artery were recorded close to the middle cerebral artery (MCA), selected on the basis of a reasonable shape at visual inspection, and phase-shift curves from tissue were obtained from manually selected regions of interest (ROIs) in grey matter. Background correction was performed separately on tissue and arterial phase data by subtracting a phase-shift curve (located close to the curve to be corrected) that displayed no obvious response to the contrast agent. The deconvolution of background-corrected tissue and arterial phase-shift time curves resulted in an approximate tissue residue function R(t). The peak value of R(t) was used as a relative CBF index, while the area-to-height ratio of R(t) provided quantitative mean transit time (MTT) estimates. ASL-based CBF estimates were acquired using a QUASAR sequence [3], with repetition time 4000 ms, TE 23 ms, ΔTI 300 ms, TI_1 40 ms and matrix size 64×64. ASL CBF values were recorded in grey-matter ROIs of similar location as in the phase-shift maps.

Results

Typical phase-shift curves from single pixels in grey matter and in the vicinity of the MCA are shown in Figure 1, indicating quite reasonable SNR levels. CBF information obtained from phase images were compared with the corresponding CBF estimates from ASL (Figure 2). The degree of linear correlation between the datasets was quite satisfactory (r=0.81), and the linear equation showed a very small y-axis intercept, confirming that experimental data showed the expected proportionality between the two modalities. Grey-matter MTT was 5.4±1.9 s (mean±SD, n=14).

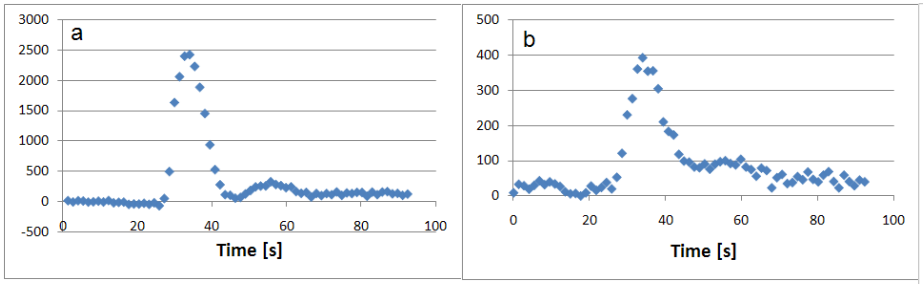

Figure 1. Phase-shift curve from a single pixel representing (a) artery and (b) grey matter.

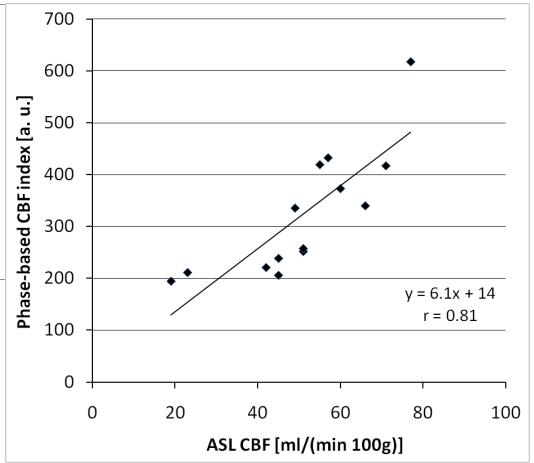

Figure 2. Phase perfusion index versus ASL CBF.

Discussion

It is indeed encouraging that a correlation exists between phase-based perfusion-related information and quantitative CBF values obtained by ASL. Unfortunately, the net phase shift of a tissue voxel shows a non-trivial dependence on the geometry and orientation of the local capillary network, and this seems to prohibit absolute quantification of CBF at present. The obtained quantitative MTT estimates for grey matter were, however, in good agreement with literature [4], indicating that the AIFs employed in the present study had reasonable shape. Rescaling of dynamic susceptibility contrast (DSC) MRI results with a phase-based perfusion index from a well-defined tissue ROI, in order to achieve more robust and reproducible DSC-MRI estimates is thus potentially of relevance. Position-dependent variations in the phase response, not related to the hemodynamics, might also provide information about variations in capillary topography between different types of tissue.

References: [1] Akbudak & Conturo, MRM 1996;36:809-815; [2] Conturo et al., MRM 1992;27:375-390; [3] Petersen et al., MRM 2006;55:219-232; [4] Leenders et al., Brain 1990;113:27-47.