Flow-Dephased and -Rephased Diffusion-Weighted fMRI with Weak Flow Weighting

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Introduction

Flow-rephasing (FR) and -dephasing (FD) applied to functional magnetic resonance imaging (fMRI) [1] is a technique where the gradient scheme of diffusion-weighted fMRI [2,3] is either flow compensated (FR), or will maximally dephase moving spins (FD) [4-6]. Thereby, it is possible to use deoxygenated hemoglobin as an endogenous contrast agent via the blood oxygenation level dependent (BOLD) effect in order to study the dynamics, i.e. different regimes of flow, in the venous network. In the previous work [1], relatively high flow weighting (FW) of M_1 = 50-4500 s/m was added to a spin-echo (SE) EPI sequence (first gradient moment $M_1 = \gamma \int G(t) t dt$). This corresponds to *b*-values of 14-454 s/mm². It was found that a significant difference in fMRI signal exists between the FD and FR measurement which can be attributed to ballistic flow, i.e. flow with no change of direction or velocity during *TE*. This difference remained constant over the whole range of M_1-values. It was suggested that the component with ballistic flow is associated with the capillaries due to their lower velocity. However, because the exact dependency of the difference in fMRI signal on M_1 was not assessed, this remains speculative. Therefore, fMRI FD/FR with very low M_1-values was repeated in this work to investigate the exact M_1-dependency in order to determine the source of ballistic flow.

Materials and Methods

Experiments were performed on a Siemens 3T Trio system using the ODIN framework [7] for sequence design. The layout of the SE EPI sequence was the same as described in [1], but with slightly different parameters: *TE* = 39 ms, *TR* = 1050 ms, 64 × 64 matrix, 190 mm FOV, 5 slices (4mm thickness, 1 mm gap), 80% of *k*-space acquired (partial Fourier). The M_1-values were 15, 24, 37, 58, 95, and 150 s/m (corresponding to *b* = 0.06, 0.09, 0.18, 0.40, 1.00, and 2.43 s/mm²). The flow-weighting gradients were oriented in read direction. The FD and FR variant of all six M_1-values was acquired during one fMRI trial in an interleaved fashion together with a standard SE EPI measurement to determine activated voxels. Their order was rotated during the trial to avoid systematic errors due to the delay of the BOLD response. 11 subjects were studied with visual stimulation as described in [1] which was switched on for 36 × *TR* followed by a resting period of the same duration. This block was repeated six times during one trial. Four trials were acquired per subject. Activated voxels were indentified by linear correlation and a threshold of $p = 0.001$ for error probability. Voxels with less than two activated neighbours were discarded. Calculated signal changes for each M_1-value were averaged over all subjects, trials, and stimulation blocks.

Results

The fMRI signal change is plotted in Fig. 1. The flow-rephased data, which can be assigned to diffusive flow, was modelled by a single exponential decay (Eq. 1 in [1]), yielding an apparent diffusion coefficient ADC = $106 \cdot 10^{-3}$ mm²/s (solid line in Fig.1). The difference between FD and FR, which can be assigned to ballistic flow, was fitted to a function which describes the attenuation of isotropic laminar flow as a function of M_1 (Eq. 5 in [1]). Thereby, a mean velocity of v = 0.17 m/s was obtained for ballistic flow (dashed line in Fig.1).

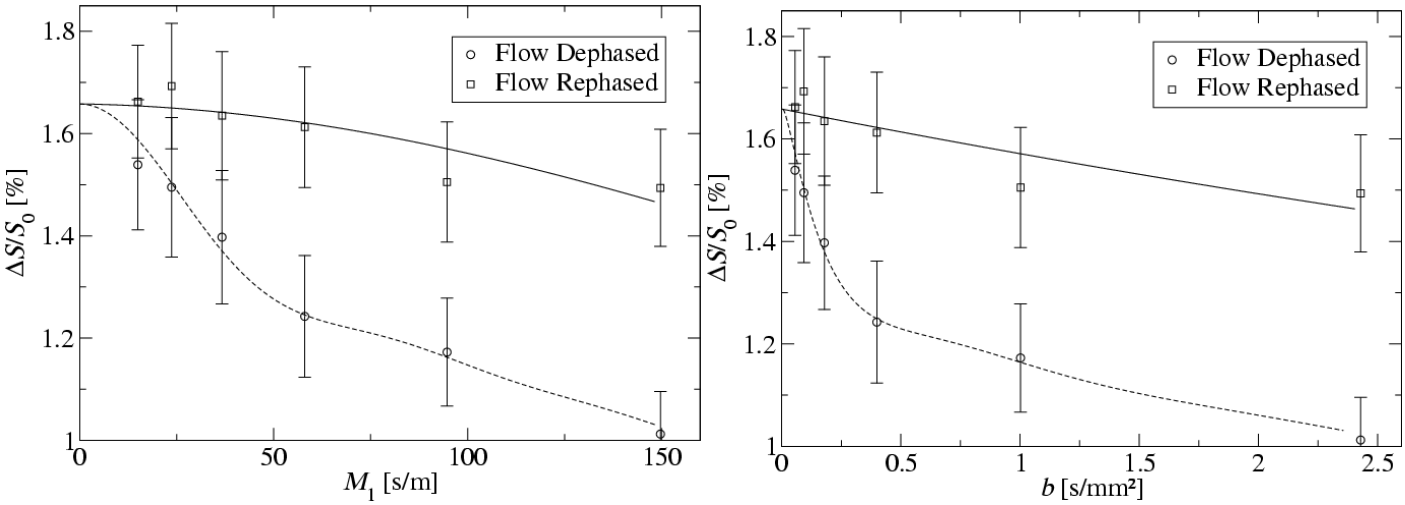

Fig. 1: Functional signal change as a function of M_1 (left) and *b*-value (right).

Discussion and Conclusions

With the high mean velocity obtained for ballistic flow, its origin are most likely draining veins [8]. The assignment of ballistic flow to capillaries, which was suggested in [1], is therefore questionable. On the contrary, a more plausible interpretation in the view of the data presented here is that ballistic flow represents large blood vessels, and capillaries give rise to diffusive flow. Another source of ballistic flow contributing to the fMRI contrast could be inflow effects due to larger arteries. Although this cannot be ruled out completely, a previous study with the same *TR* showed a zero-intercept when extrapolating fMRI contrast to *TE* = 0 [9], indicating the absence of inflow-effects. A flow-dephased gradient scheme with $M_1 \approx 50$ s/m and $b \approx 0.5$ s/mm² is sufficient to remove unwanted signal from ballistic flow, i.e. from larger veins, while preserving precious signal from the microvasculature.

References

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