Pulsatile Microvascular Perfusion Demonstrated in the Human Brain with Intravoxel Incoherent Motion (IVIM) MRI

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Purpose

Microvascular perfusion can be measured in the brain with Intravoxel Incoherent Motion (IVIM) MRI [1], as first proposed by Le Bihan et al [2]. By fitting a double exponential model to the diffusion sequence signal amplitude as function of b (for b < 1000 mm^2/s), one obtains 3 IVIM microvascular perfusion parameters, f, the perfusion fraction, D*, the pseudo-diffusion coefficient, and fD*, which is related to blood flow [3], as well as one non-vascular parameter D, the (thermal) diffusion coefficient. To better understand those parameters, we studied here their dependence on the cardiac cycle.

Materials and Methods

Imaging was performed on 20 healthy subjects, using a standard EPI spin echo sequence with embedded Stejskal-Tanner pulsed gradients sequence, at 3 Tesla using a 32-channel receiver head-coil, with prospective cardiac triggering. Repeat measurements were acquired with evenly spaced time delays across the whole cardiac cycle for 13 patients to compare the IVIM parameters between systole and diastole. In a further 7 subjects, the repeat measurements were evenly spaced over systole. A single axial brain slice was acquired at the level of the basal ganglia. Due to the Cardiac triggering TR was variable, but set to a minimum of 5s. Other image parameters were TE 88-92ms, 1.2x1.2mm in plane resolution, BW 1134 Hz/pixel and b-values of (0, 10, 20, 40, 80, 110, 140, 170, 200, 300, 400, 500, 600, 700, 800, 900 s/mm^2), in 3 orthogonal directions. A region of interest was then drawn around the total brain parenchyma of the axial slice, and the pixel containing cerebro-spinal fluid were excluded by thresholding the b0 image. The signal obtained was then averaged for each b-value, and fitted as previously described [1]. To evaluate the peak arrival time of the systolic pressure wave in the arteries, we measured flow in the anterior cerebral artery (ACA), in a sub-group of 7 subjects, with a retrospectively cardiac gated phase-contrast sequence ((TR/TE 14/3.14ms, Venc 100 cm/s, Voxel size 1.0x1.4x5.0 mm, 40 frames). The temporal center of the IVIM sequence was defined to be in the center of both Stejskal-Tanner gradients, which is the point where we expect the maximum IVIM perfusion effect assuming a symmetric time dependent (pseudo)-diffusion coefficient [4].

Results

A clear dependence on the cardiac cycle was observed for all 3 IVIM perfusion parameters f, D*, and fD*, while D, as expected, remained stable (**Fig 1**). During systole (defined from 0-250ms after the R-wave), D* and fD* were increased significantly compared to diastole ($D^*_{Systole}$ = 12.07 ± 9.40 ·10^{-3} mm^2·s^{-1}; $D^*_{Diastole}$ = 5.06 ± 1.91 ·10^{-3} mm^2·s^{-1}; p = 1·10^{-6}; $fD^*_{Systole}$ = 0.92 ± 0.69 ·10^{-3} mm^2·s^{-1}; $fD^*_{Diastole}$ = 0.69 ± 0.20 ·10^{-3} mm^2·s^{-1}; p = 5·10^{-5}), while f (related to the microvascular volume) was not statistically different. The global aspect of the time dependence of the flow in the ACA and the IVIM flow related parameter fD* (**Fig 2**) were similar. Mean time to peak (TTP) of fD* occurred 133 ± 15 ms after the R-peak, slightly delayed in comparison to the mean TTP flow in the ACA measured at 127 ± 18 ms (p = 0.17).

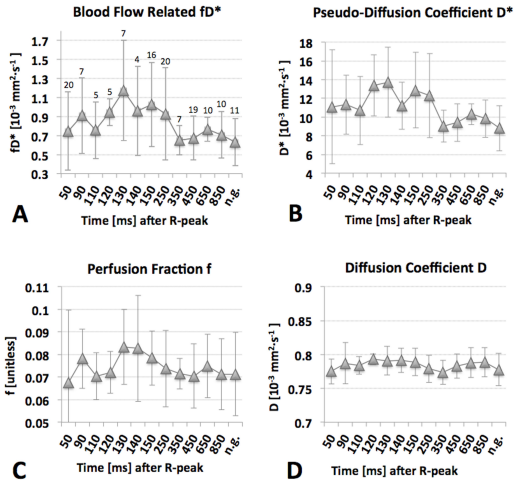

Fig 1: fD*, D*, f, and D (means ± standards deviations) as function of acquisition time post R-peak. The number of subjects averaged over is noted above each measure in **A**.

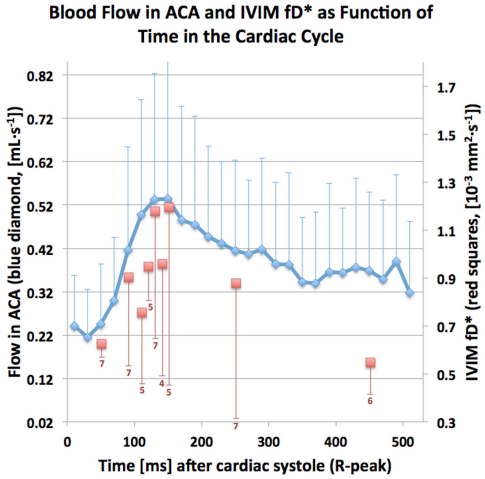

Fig 2: Data are means. For legibility, standard deviations are indicated positively for the flow in the anterior cerebral artery (ACA), and negatively for the blood flow related IVIM fD*. The number of subjects averaged over was 7 for the flow in the ACA, and is noted under each time point for IVIM fD*.

Discussion

Our findings represent direct experimental evidence of pulsatile flow in the human brain microvasculature. These results correlate well with recently reported measurement of pulsatile blood flow in the microvasculature of the cortex of the mice brain by Santisakultarm et al [5] using two-photon microscopy. In conclusion, the present results further validate IVIM as a method to measure human brain perfusion.

References

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