

Validation of Quantitative Human Brain Perfusion Measurement with Intravoxel Incoherent Motion (IVIM), with a Hypercapnia and Hyperoxygenation Challenge.

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Purpose

Quantitative brain perfusion measurement remains a major challenge to currently available MR perfusion methods. Quantification dynamic susceptibility contrast (DSC) and dynamic contrast-enhanced (DCE) MR are hampered by signal non-linearity and dependence on arterial input function. Arterial spin labeling (ASL) exhibits, in addition to a low signal-to-noise ratio, a strong dependence to transit time. This transit time can be very variable in a patient population. The intravoxel incoherent motion (IVIM) method introduced by Le Bihan et al [1] offers a non-invasive, alternative method to measure brain perfusion quantitatively. As opposed to DSC, DCE and ASL, IVIM has a unique capillary dependence, which is not sensitive to coherent laminar flow of arteries and veins. Further, IVIM's measurement is intrinsically local: the encoding and readout are done at the same location. We tested the IVIM method in 7 healthy volunteers under graded hypercapnia (a well known potent powerful intra-cerebral vasodilator, leading to an increase of cerebral blood flow) and under hyperoxygenation (shown to significantly decrease cerebral blood flow) [2].

Materials and Methods

The IVIM method is based on a bi-exponential fit (*) of the relative signal obtained with the Stejskal-Tanner diffusion sequence [3] for multiple b-values, which permits the extraction of the perfusion-fraction f and the pseudo-diffusion coefficient D*. D is the diffusion coefficient, and S₀ = S(b=0).

$$\frac{S(b)}{S_0} = fe^{-bD^*} + (1 - f)e^{-bD} \quad (*)$$

We acquired 16 different b-values (0, 10, 20, 40, 80, 110, 140, 170, 200, 300, 400, 500, 600, 700, 800, 900 s/mm²) that are acquired in 3 orthogonal directions using a 3 Tesla MR scanner and a 32-multichannel receiver head coil. TR/TE = 4000ms/99ms, 4 averages, voxel size = 1.2 x 1.2 x 4 mm, total acquisition time = 12:28 min. In 2 healthy volunteers we investigated the variation of the IVIM parameters in the brain after inhalation of normal ambient air (22% O₂, 78% N₂), and a mixture of 5% CO₂ and air (5% CO₂, 22 % O₂, 73% N₂), and in 5 healthy volunteers, after inhalation of ambient air (22% O₂, 78% N₂), a mixture of 5% CO₂ and air (5% CO₂, 22 % O₂, 73% N₂), and 8% CO₂ in normal ambient air (8% CO₂, 22 % O₂, 70% N₂), as well as pure oxygen (100% O₂).

Results

Signal decay curves were bi-exponential in the brain parenchyma of all volunteers. The perfusion fraction f and the pseudo-perfusion D* increased statistically significantly with incremental percentage of inhaled CO₂ in healthy volunteers (p < 0.05), and decreased while inhaling pure oxygen (although with p > 0.05).

Conclusion

The IVIM method is a valid method to measure brain perfusion quantitatively. Its major advantages in comparison to other techniques are: direct sensitivity to blood flow within the capillary bed (independent of arterial transit and venous blood volume); independence of iv-contrast injection; and robustness of the Stejskal-Tanner pulse sequence. These properties are key advantages for the IVIM method to become a practical perfusion imaging technique in the clinical setting.

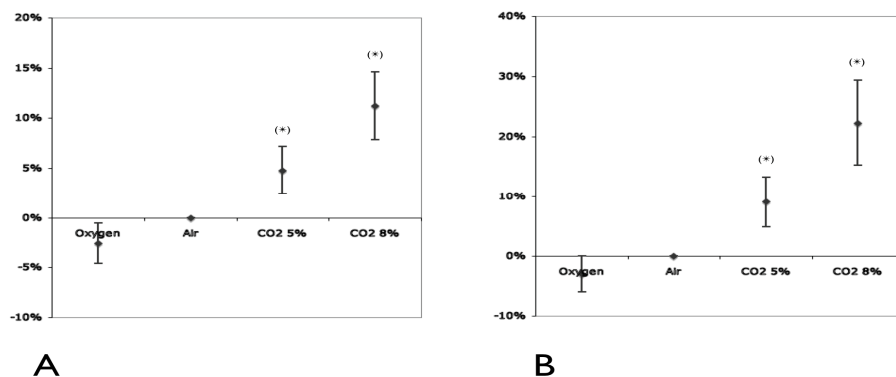


Fig 1: (A) Variation of the perfusion fraction f and (B) the pseudo-diffusion coefficient D* under different gas mixtures inhalation. (*) means p < 0.05. Shown are means and standard deviations of the average of all pixels over the full covered brain in all volunteers.

Reference

[1] Le Bihan, D., et al., *Separation of diffusion and perfusion in intravoxel incoherent motion MR imaging*. Radiology, 1988. 168(2): p. 497-505. [2] Kety, S.S. and C.F. Schmidt, *The effects of altered arterial tensions of carbon dioxide and oxygen on cerebral blood flow and cerebral oxygen consumption of normal young men*. J Clin Invest, 1948. 27(4): p. 484-92. [3] Stejskal, E.O. and T. J.E., *Spin Diffusion Measurements: Spin Echoes in the Presence of a Time-Dependent Field Gradient*. J Chem Phys, 1965. 42(1): p. 288-292.