Investigation of Susceptibility-Induced MR Signal Dephasing in Phantom Measurements and Model Simulations for Oxygen Extraction Mapping

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Introduction:

A recent approach to map Oxygen extraction fraction (OEF) in tissues is to measure susceptibility differences between venous vessels and surrounding tissue by using combined spin-echo/gradient-echo sequences. The signal decay from such measurements is usually modelled by a static dephasing model to predict the relative volume fraction of the blood vessels and reversible relaxation rate R_2' [1]. From these values OEF maps are calculated [2]. To get valid results from such measurements it is important to investigate the model underlying these calculations.

Hence, in this work a phantom study was performed to investigate the signal decay around a spin echo for capillary inclusions of different radii in a homogeneous medium. The signal time courses were compared and fitted with the commonly used static dephasing model [1] and with an extended model to additionally incorporate diffusion effects [3].

Methods:

A custom-built phantom consisting of 8 compartments filled with randomly coiled Nylon strings in a $NiSO_4$ solution was used to simulate the properties of brain parenchyma with statistically distributed capillaries within homogeneous tissue. Each compartment contained a filament with a distinct radius (r_c= 13.5µm, 19µm, 24µm, 33µm, 44.5µm, 72µm, 97µm, 119µm) in a relative volume faction of $\lambda \approx 5\%$. The signal decay due to the inclusions was investigated by means of a home-built multi gradient-echo/spin-echo imaging sequence. With the latter the signal was sampled symmetrically around a spinecho (TE_{SE}=136ms) by 32 gradient-echoes with an echo spacing of ΔTE=4ms. Other sequence parameters were: 1.GE: TE_{GE1}=76ms, RO-bandwidth=500Hz, TR=2000ms, FOV=192x192mm, Matrix=128x128, $\Delta x=\Delta y$=1.5mm, Δz=8mm. To enhance SNR of the data 32 averages were acquired in a total measurement time of 2h 16min. T2 values of the phantom were determined in separate measurements using a 32 SE CPMG-sequence. The data values from each compartment were averaged in a circular ROI.

To compare the measured data with theoretical decay models and to investigate the influence of diffusion for different capillary radii on the signal decay, simulations were performed by solving the signal attenuation integral for two distinct analytic models: The static dephasing model by Yablonskiy [1] and an extended model, which additionally incorporates the effects of spin diffusion around the capillaries [3]. For the simulations all parameters were fixed to predefined values, which were either taken from the preadjustments or measured beforehand. After the simulation the results were only scaled to fit the data. The following values were relevant for the model calculations: T2=111ms, $\Delta\chi=0.55*10^{-7}$, D=2.3 µm^2/ms, Volume fraction = 5%.

Results:

The measured signal decay curves generally showed a systematic curvature dependency on capillary radius. So, fitting with a monoexponential in the longterm regime as commonly used to determine susceptibility differences and OEF values [4, 5] exhibited systematic deviations from the data. The logarithmic data for smaller capillary sizes below r_c = 40µm indicated significant nonliniarities before the spin-echo which can not be explained by simple static magnetisation dephasing.

In Fig 1 two measured signal decay curves are shown exemplary for r_c = 13.5µm and r_c = 97µm. For comparison the model simulations for the static dephasing model and the extended model including diffusion are depicted. As can be seen, for larger capillary radii both models fit the data reasonably well, although inclusion of water diffusion enhances the agreement slightly. For smaller capillary radii, the static dephasing model completely fails to explain the experimental data. A much better explanation for the measurement results is provided by the simulation using the model including diffusion effects, although with still notable deviations.

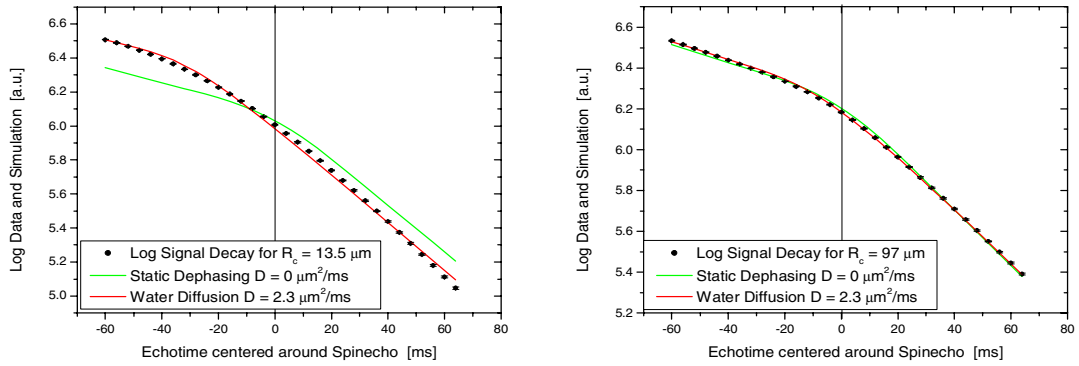

Fig. 1 Measured timecourses for two different radii with scaled model simulations for the static dephasing model and the diffusion model.

Discussion:

In this work phantom measurements and model simulations were performed to investigate the influence of diffusion on signal behaviour in gradient-echo/spin-echo sequences. Our experiments show a significant influence of water diffusion on the signal decay especially for smaller capillary sizes in the range lower than 40µm. While static dephasing approximation fails to explain the data in this range a realistic diffusion model yields a fairly good agreement with the data. This has an important impact on simple techniques using the static dephasing approximation to determine OEF e.g. in brain tissue [2], since this model does not fit the data well. Due to diffusion, the characteristics of the relaxation curves become dependent on capillary radius, and hence the determination of OEF depends on the a priori knowledge of the capillary radius-distribution in tissues. This might be a general problem for in vivo OEF measurements using reversible relaxation rate measurements and the values obtained by the static dephasing approximation might have to be questioned.

References:

[1] Yablonskiy, Haacke, *Magn Reson Med* **1994**, *32*, 749. [2] H. An,W. Lin, *Magn Reson Med* **2002,** *47*, 958. [3] Kiselev, Posse, *Magn Reson Imaging* **1999**, *41*, 499. , [4] Bongers, Schad, Proc. Intl. Soc. Mag. Reson. Med. (ISMRM) **2004** *11*, Kyoto, Japan, 1083. [5] Yablonskiy, *Magn Reson Med* **1998**, *39*, 419.