Uncertainty in Simultaneous Estimation of Blood Oxygenation Level and Volume Fraction on the Basis of Spin Dephasing in a Vascular Network.

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Introduction: Blood oxygenation level (Y) and volume fraction (λ) are essential input parameters of theoretic models of spin dephasing in a vascular network [1]. It is possible to estimate these parameters by fitting the simulated signal to measured signal-time curves. First *in vivo* applications of the model of spin dephasing in a vascular network obtained reasonable, but not independently proven, oxygenation levels of Y≈70% in the human brain [2]. A first step to validate this method has already been taken by performing well defined phantom experiments, in which all parameters describing the network were known [3]. However, if Y and λ are unknown, they can not be reliably estimated by simply fitting theoretical signal curves to the measured signal decay. The purpose of this work was to unravel this difficulty of a simultaneous estimation of Y and λ.

Methods: The signal-time curve of the model was calculated according to Eqs. A15 and A16 in [1] using the following parameter set of λ=5%, Y=55%, T_2=100ms, hematocrit=0.45 and $\Delta\chi_{do}$=0.18ppm(cgs). The latter is the difference in magnetic susceptibility between fully oxygenated and deoxygenated red blood cells [4]. *In vivo* signal-time curves were measured in gray and white matter in healthy human brain by using a gradient echo sampled spin echo (GESSE) sequence [5]. The signal was sampled for T_E=40-210ms with an inter echo distance of ΔT_E=4ms. The spin echo occurred at $T_{E\,SE}$=68ms. The acquisition matrix was 182x96 with a FOV of 256x192mm² and the slice thickness 3mm. ROIs were drawn in homogeneous parts of gray and white matter by carefully omitting voxels including cerebrospinal fluid or larger vessels.

Results: Fig.1 shows the calculated signal decays for a subset of different Y and λ pairs, where Y was set to 25, 50 and 75% and λ to 2.5, 5 and 7.5%. As can be seen some signal curves nearly coincide although they were calculated with different Y and λ pairs. Fig.2 shows the contour plot of the root mean square error (MSE) between the signal curve calculated for λ / Y=5% / 55% and the curves obtained with parameter ranges of λ=0 to 10% and Y=0 to 100%. The plot shows low values for a wide range of λ / Y pairs (dark region in Fig.2). Fitting the simulation to *in vivo* signal curves resulted in minimal MSEs for combinations of λ / Y=2.1% / 72% for white and λ / Y= 2.6% / 66% for gray matter. Fixing the venous blood volume fractions to 1.5% for white and 3% for gray matter [6,7] yielded also low MSEs for blood oxygenation levels of 67% for white and 69% for gray matter.

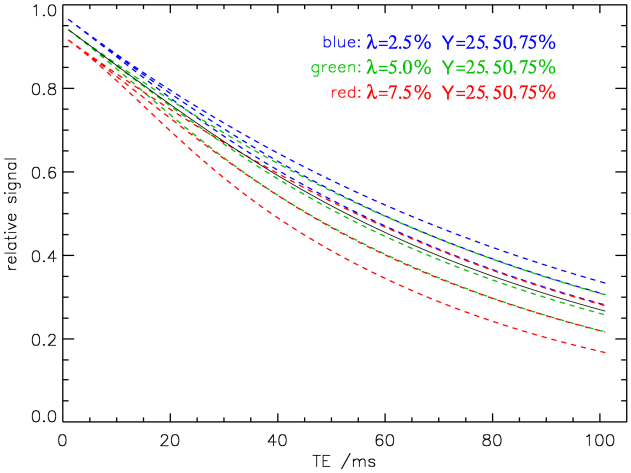

Figure 1: Signal decay of a capillary network with λ=5%, Y=55% and T_2=100ms at 1.5T (solid black line) flanked by signal decays calculated with different λ / Y parameters, where the upper curve of each color (λ) was calculated with the highest blood oxygenation level (Y=75%) and the lowest curve with the lowest blood oxygenation level (Y=25%).

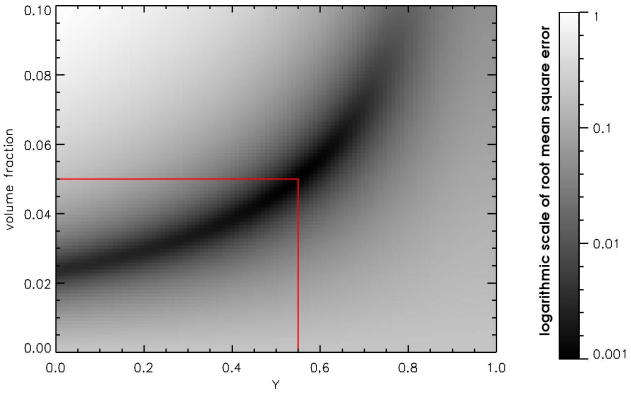

Figure 2: Contour of root mean square error between the signal curve of the parameter set λ/Y=5% / 55% (red marks) and all other curves for λ=0 to 10% and Y=0 to 100%.

Discussion: The nearly coinciding signal curves, calculated with different λ / Y parameter pairs, make it difficult to find the true λ / Y pair if both parameters are optimized simultaneously by a fitting routine. This leads to *in vivo* λ / Y parameter combinations which are not consistent with literature [2,6,7]. However, fixing the venous blood volume fraction (λ) to 1.5% for white and 3% for gray matter [6,7] yields reasonable blood oxygenation levels of Y≈70% for both white and gray matter which are comparable to literature [2]. He and Yablonskiy [2] obtained very low λ-values of 0.6% for white and 1.5% for gray matter. If we assume the same low λ-values, we obtain blood oxygenation levels of only Y≈50%. This discrepancy is caused by the used hematocrit and $\Delta\chi_{do}$-value for the calculation of the blood oxygenation level. If we recalculate our blood oxygenation level with the same $\Delta\chi_{do}$-value as He and Yablonskiy [2] ($\Delta\chi_{do}$= 0.27ppm(cgs) [8]), the blood oxygenation level becomes Y≈70% which is again in agreement with the results of He and Yablonskiy [2].

Conclusion: So far, no clear separation of the blood oxygenation level (Y) and its volume fraction (λ) is possible by simply fitting theoretic simulations to measured signal decays which are caused by spin dephasing in a vascular network. An independent determination of the venous blood volume fraction should help to obtain reliable blood oxygenation levels. The estimation of blood oxygenation levels from MR signal decays has to be further verified; for example, in animal experiments where the oxygen tension can be independently determined by performing microelectrode measurements.

Literature: [1] Yablonskiy DA and Haacke EM, MRM 32:749-763, 1994. **[2]** He X and Yablonskiy DA, MRM 57:115-26, 2007. **[3]** Sedlacik J, et al., Proc.ISMRM 15:2080, 2007. **[4]** Weisskoff RM and Kiihne S, MRM 24:375-383, 1992. **[5]** Yablonskiy DA, MRM 39:417-428, 1998. **[6]** Moskalenko YE, *Biophysical aspects of cerebral circulation*. Pergamon Press, Oxford, 1980. **[7]** Yamaguchi T, et al., Stroke, 17:1220-1228, 1986. **[8]** Spees WM, et al., MRM, 45:533-542, 2001.