Evaluation of a new qBOLD approach to map local blood oxygen saturation in human brain

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Introduction

qBOLD (quantitative Blood Oxygen Level Dependent) [1] allows quantitative evaluation of cerebral tissue hemodynamic parameters , such as the blood volume (BVf), deoxyhemoglobin concentration or local oxygen saturation (lSO2). A simpler approach that combines separate estimates of T_2, T_2*, BVf, and B_0 inhomogeneities has recently been proposed and validated in rats [2]. The aim of this study is to evaluate this approach on the non-lesioned tissue of patients at 3T.

Materials and Methods

lSO2 in a voxel can be calculated according to the following equation 1 [2]:

$$lSO2 = 1 - (4/3.\pi.\gamma.\Delta\chi_0.Hct.T_2'.BVf)^{-1} \quad \text{where} \quad 1/T_2' = 1/T_2^* - 1/T_2$$

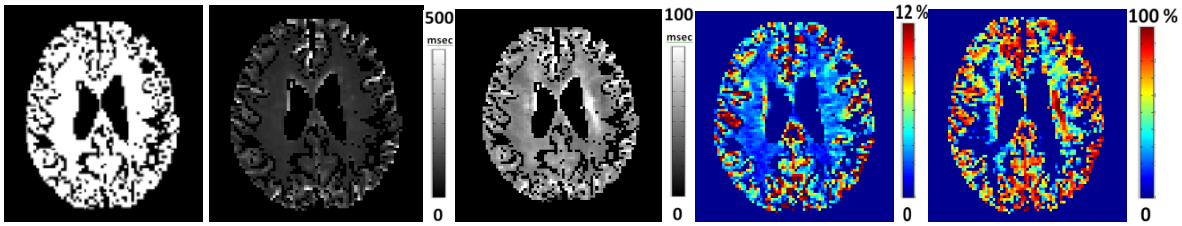
and T_2 is the transverse relaxation time for parenchyma tissue, ΔX_0=0.264ppm is the difference in magnetic susceptibilities between fully oxygenated and fully deoxygenated hemoglobin, and Hct=0.42 is the hematocrit fraction.

Three stroke patients, beyond the acute phase, and one arteriovenous malformation (AVM) patient were studied after written informed consent was obtained. All images were acquired on a Philips Achieva 3T TX.

Acquisition. In addition to a 3DT1sequence used for tissue segmentation (TR/TE=9.8/4.6ms, resolution=0.5x0.5x1mm), three sequences were acquired with a FOV of 224x20x184mm: a 3D multi gradient echo (GE) sequence to correct static field inhomogeneities (25 slices, resolution= 1x1x0.8mm, 23 echoes, TR=164msec, ΔTE=7ms); a multiple spin-echo experiment for T_2 mapping (5 slices, TR=1282 ms, 32 echoes, ΔTE=9ms, resolution=2x2x4mm); a perfusion sequence with injection of 0.1mmol/kg of Gadolinium (Guerbet, France) for BVf mapping (TR=1041ms,dynamic scan time= 1.04sec, resolution=2x2x4mm).

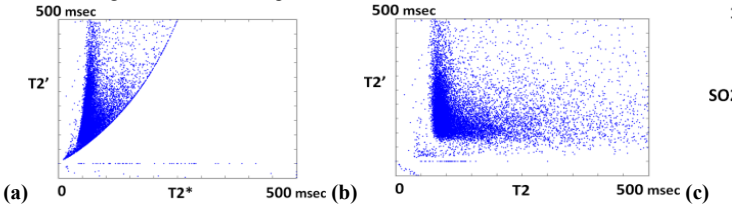
Data Analysis. T_2 and T_2* maps were obtained by fitting a monoexponential decay to the corresponding MR images. Relative BVf maps were obtained by fitting a gamma-variate function to the relative change in T_2* over time during Gd-bolus passage. To obtain quantitative BVf maps, the mean brain blood volume was normalized to 5%. SO_2 maps were eventually calculated withEq 1 pixelwise. Then, using SPM8 [3], gray (GM) and white matter (WM) masks were obtained (Fig 1a.) from the 3DT1 images. The masks were realigned and resliced to match the T_2 map (1b). Since masks were obtained with values between 0 and 255, a threshold of 204 was set to further select GM and WM pixels from the GM and WM masks. In this process, the lesion was excluded from the analysis.

Figure 1. Maps obtained in one patient at 3T (The displayed slice does not contain any lesion).



(a) GM +WM Mask **(b) T_2map** **(c) T_2*map** **(d) BVfmap** **(e) lSO2map**

Figure 2. For one representative patient and for gray and white matters, correlation between (**a**) T_2* and T_2' (**b**) T_2 and T_2'. (**c**) BVf and SO_2. (**d**) T_2*, T_2, BVf, and lSO2 values averaged across the four patients for GM mask, WM mask and the combination between GM and WM masks (mean±standard deviation).



	GM		WM		GM WM	
	Mean	SD	Mean	SD	Mean	SD
T2*	61	7	54	6	58	7
T2	120	20	87	8	104	18
BVf	6	1	3	1	5	1
lSO2	57	5	34	3	45	4

Results

Fig. 1 shows representative mask and maps obtained in the non-lesioned tissue from one patient. The noise level in maps is low. The interpatient variabilities for T_2 and T_2* are 12% and 17% respectively. Maps reflect the gray/white matter anatomy. Average T_2* and T_2 values measured in gray (61±7 and 120±20ms) and white (54±6 and 87±8ms) matters correspond to what has been reported in the literature [4]. BVf was 6% in GM and 3% in WM (Fig. 2d). lSO2 values in GM, WM or both were 57±5%, 34±3%, 45±4% respectively. lSO2 was higher in the AVM (data not shown) and lower in stroke lesion.

Interestingly, for all subjects, T_2*, T_2', and T_2 were not correlated (Fig. 2a-b); neither were lSO2 and BVf (Fig. 2c). This absence of correlation suggests that lSO2 provides additional information to T_2, T_2', and BVf. One however observes that for reduced BVf, lSO2 decreases.

Discussion / Conclusion

lSO2 values obtained by MR in humans appear reproducible and match, for gray matter, those reported in the literature for humans [5] and those obtained in rats using the same MRI approach [2]. In white matter, these values are lower than expected. This might be ascribed to three phenomena. (**i**) The BVf estimate in WM may be erroneous since a coarse normalization factor was used in this study. (**ii**) The susceptibility gradient between deoxygenated blood and WM may differ from that described by ΔX_0. (**iii**) Microvessels in WM may follow specific directions, thereby violating the assumption made in the model that vessels are randomly orientated [1]. In conclusion, this study shows that cerebral blood oxygen saturation may be measured in a single MR exam from three MR sequences with good spatial resolution. Further studies are required to validate this promising approach in humans and improve the estimates obtained in white matter.

References

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(5) An et al JCBFM 2000.