

## Brain Oxygen Saturation assessment using T2 Prepared Diffusion Imaging

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**INTRODUCTION:** Blood oxygen saturation in the brain tissue is an important parameter in the evaluation of patients such as stroke or asphyxiated newborns. In the neonates this is routinely monitored using bedside near-infrared spectroscopy however with a relative coarse resolution or “banana” shape region as illustrated in Fig. 2a. Whereas this is sufficient for clinical monitoring and assessment, it is desirable to get regional information when investigating the etiology of a disease or in for instance adult stroke, where the penetration depth of NIRS is a limitation. Techniques such as MEGESE [1] have been developed for measuring oxygen saturation (Y) and regional OEF. Quantification is based on modeling of T2 and T2\* in a two-compartment model, in which the extravascular and intravascular compartments correspond to brain tissue and venous blood vessels. If the vascular blood T2 could be measured more directly possible sensitivity to field inhomogeneity and model assumptions could be limited. Perfusion-related parameters obtained by intravoxel incoherent motion (IVIM) imaging [2] have previously been compared with cerebral blood volume and flow (CBV and CBF), retrieved by dynamic susceptibility-contrast MRI and showed reasonably agreement with each other [3].

In this work we present a method which allows measurement of blood T2 in the tissue using a “T2 Prepared Blood IVIM Imaging of Oxygen Saturation” (T2-BIOS) sequence from where bloods oxygen saturation can be estimated. The IVIM effects in diffusion weighted imaging are exploited in a T2 prepared DWI sequence to separate the blood signal. Using previous determined relationships of T2 versus Y [4,5], one can potentially generate an oxygen saturation map. In the neonates this is what corresponds to the information obtained from NIRS.

**METHODS:** The T2-BIOS sequence is shown in Fig. 1. Initially the longitudinal magnetization is T2 prepared using a standard MLEV preparation [4]. Subsequently, a standard Stejskal Tanner diffusion sequence is played out in one of x, y or z directions. The sequence is repeated in groups of 4, each with an effective MLEV TE preparation of 0, 40, 80 or 160 ms. This corresponds to 0, 4, 8 and 16 refocusing pulses using an interpulse time ( $\tau_{CPMG}$ ) of 10ms. Low and high b-value images in all desired directions are acquired for each effective echo time.

For fitting bloods T2b, the signal from the high b-value scans are first subtracted from the low b-value scans, essentially forming four  $\Delta b$  (eTE) images. These are strongly vascular weighted as long the high b-value is chosen within the intravoxel incoherent motion regime ( $< b \sim 150$ ):

chosen within the interval of incoherent motion regime ( $\tau_c < 100$ ).  

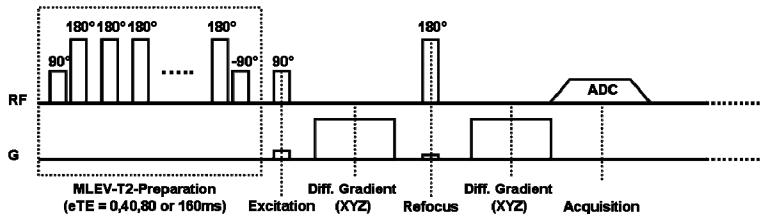
$$\Delta b(eTE) = V_b \cdot M_{0b} \cdot e^{-\frac{eTE}{T_2^*}}$$
 where  $eTE$  is the effective MLEV echo time,  $V_b \cdot M_{0b}$  is a pseudo blood volume times bloods equilibrium magnetization and for this purpose they are considered a single constant. With appropriate knowledge of  $M_{0b}$ , a pseudo blood volume can be obtained [3]. Magnetization is allowed to fully recover between repetitions. Estimation of oxygen saturation was done by the use of eq.1 in [5].

Four healthy volunteers and 7 neonates were scanned (3T Philips Achieva) using T2-BIOS according to institutional guidelines. The scan parameters were: TR/TE =8000/41ms 64x64 matrix, FOV=240x240, flip-angle=90°, 6mm slice, SENSE=2.5, eTE=0.40,80 and 160ms,  $b=0$  and  $b=50$  in x,y,z directions. Total scan time 4:32.

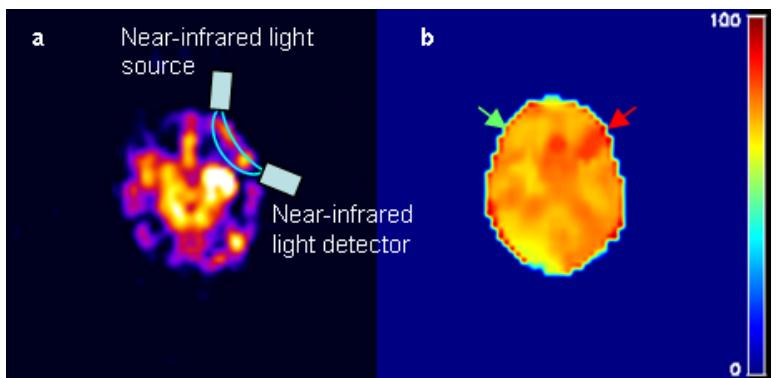
**RESULTS and DISCUSSION:** Figure 2a shows the CBF map obtained by arterial spin labeling as well as an approximate origin of the NIRS acquired data. Fig. 2b shows an example oxygen saturation map in a neonate with a left MCA infarct. Table 1 shows the corresponding oxygen saturation obtained using T2-BIOS from the healthy volunteers as well as the neonates. Near infrared spectroscopy, arterial oxygen saturation using pulse oximetry and haemoglobin NIRS are within the same range, the correlation is not significant and further op-

**CONCLUSION:** A method for oxygen saturation mapping has been proposed. Initial results show similarity with NIRS, although not significantly correlated in this small population. Further validation work is ongoing in healthy subjects using a reactivity challenge as well as in neonates where it is compared to near infrared spectroscopy while correcting for parameters such as haematocrit and arterial oxygen saturation.

**REFERENCES:** [1] An H et al, JCBFM 2000;20:1225-36 [2] Bihan D et al, MRM 1992;27:171-78 [3] Wirestam et al. Acta Rad. 1997;38:961-964 [4] Lu H et al, MRM 2008;60:357-63 [5] Lu H et al, MRM 2011 (Online)



**Figure 1.** Sequence for blood T2 measurement. The sequence is repeated 4 times, each with a different T2-preparation for each of the IVIM diffusion directions applied. This results in effective TEs of 0, 40, 80 and 160ms for all directions.



**Figure 2.** Neonate suffering a left MCA infarct. **a)** Arterial Spin Labeling CBF map with approximate location of NIRS measurements are depicted. **b)** Oxygen saturation map. Near infra-red spectroscopy revealed asymmetric oxygen saturation with 91% on the left and 67% on the right. At the approximate same regions, T2-DIOS measured 86 and 71% respectively.

**Table 1.** (H=Healthy Adult, N=Neonatal Patient, Osat = Oxygen saturation, Htc=Haematocrit. Values in brackets were assumed)

Subject	T2-BIOS Osat [%]	NIRS Osat [%]	Htc. [%]	Arterial Osat [%]
1 (H)	73	-	(44)	(98)
2 (H)	76	-	(44)	(98)
3 (H)	70	-	(44)	(98)
4 (H)	69	-	(44)	(98)
5 (N)	74	76	33	92
6a(N)	82	80	49	96
6b(N)	80	81	46	96
7 (N)	79	59	(44)	92
8 (N)	80	-	29	90
9 (N)	77	72	42	89
10 (N)	72	75	(44)	(98)
11 (N)	76	65	47	(98)