Quantitative Cerebral Blood Volume (CBV) measurement in steady state using IR true FISP - fast T1 measurement and water exchange minimized method

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Introduction

Regional cerebral blood volume (CBV) measurements are indicative of pathology of brain such as stroke, head trauma, neoplasia, Alzheimer's disease. CBV measurements in steady state (CBV_{SS}) can give absolute (i.e. quantitative) values of as opposed to the relative CBV (rCBV) measurement in dynamic susceptibility contrast (DSC) analysis [1, 2]. However, it is well known that CBV_{SS} values depend on water exchange rate [3]. We present a novel method to measure quantitative CBV_{SS} ($qCBV_{SS}$) using fast T1 measurement from true FISP readout of inversion recovery (IR true FISP). Our CBV measurement also employs a water exchange minimized calculation that has proven to reduce the error associated with water diffusion.

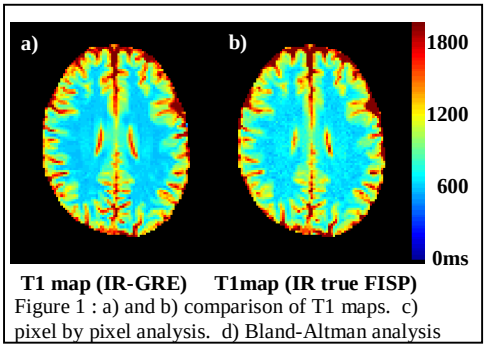

Figure 1 : a) and b) comparison of T1 maps. c) pixel by pixel analysis. d) Bland-Altman analysis

Method

There are two water exchange rate models to measure CBV_{SS}. The one is "the fast water exchange rate" model and the other is "no water exchange rate" model. In the fast water exchange limit, CBV can be calculated by the ratio of T1 rate change in a tissue to T1 rate change in a blood pool. In the no water exchange limit, CBV can be calculated by the ratio of signal changes in tissue and blood pool. Using a hematocrit correction factor, absolute CBV values can be obtained in each method.

$$CBV_{SS}^{FastEx} = 100 \times \frac{k_H}{\rho} \times \frac{1/T_{1\,post-contrast}^{tissue} - 1/T_{1\,pre-contrast}^{tissue}}{1/T_{1\,post-contrast}^{blood} - 1/T_{1\,pre-contrast}^{blood}}, \quad CBV_{SS}^{NoEx} = 100 \times \frac{k_H}{\rho} \times \frac{S_{pre-contrast}^{tissue} - S_{post-contrast}^{tissue}}{S_{pre-constrast}^{blood} - S_{post-contrast}^{blood}}$$

where $T_{1\,pre/\,post-contrast}^{tissue/blood}$ and $S_{pre/\,post-contrast}^{tissue/blood}$ are T1 and signal intensity in tissue / blood before and after contrast injection respectively, ρ is an average density of the brain (1.04g/ml), $k_H = (1-H_{LV})/(1-H_{SV})$ and $H_{LV,SV}$ are hematocrit values in large/small vessel (0.45/0.25).

Donahue et al represented no exchange, exchange minimized IR (nEM-IR) method (TI ~ 100ms) is better than fast exchange, exchange minimized IR (fEM-IR) method by simulation [3]. We have compared fEM and nEM-IR true FISP methods for qCBV measurement. Small flip angle makes the signal of IR true FISP regrow following a pure T1 recovery [4]. T1 values for fEM-IR true FISP are estimated by fitting up to the null point into mono-exponential equation because the former part of signal recovery curve is less sensitive to water exchange rate. Signal at 100ms for nEM-IR true FISP was calculated by the signal intensity from fitting equation, which was solved by fitting up to the null point.

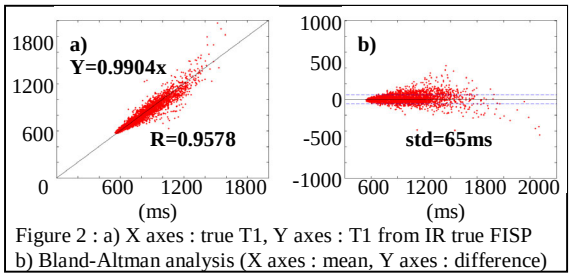

Figure 2 : a) X axes : true T1, Y axes : T1 from IR true FISP b) Bland-Altman analysis (X axes : mean, Y axes : difference)

We measured T1 values of 10 water phantoms with different gadolinium concentration and the brains of 5 volunteers using IR true FISP and compared true T1 values which were obtained from IR-gradient echo (IR-GRE) sequence with 7 different inversion times.

Water exchange effects in measurement of CBV_{SS} values were simulated. IR T1 recovery was simulated with 3 different water exchange rates (1, 5, and 10/sec). CBV_{SS} values were calculated from T1 measurement by fitting whole curve and from signal difference at t = 0.8 sec for normal method

We scanned 5 volunteers before and after gadolinium injection with segment IR true FISP sequence (non-selective IR pulse, 20 linear ramp preparation pulses before train of ± alpha° pulses, TR/TE = 2.91ms/1.46ms, total scan time = 2.08 min)[5]. T1 values were calculated pixel by pixel by fitting up to the null point and compared with true T1 values from IR-GRE sequence. CBV was measured in fEM and nEM-IR true FISP methods. ROI was chosen in gray matter (GM) and white matter (WM) based on calculated T1 values (550ms<T1<650ms for WM, 700ms<T1<1000ms for GM).

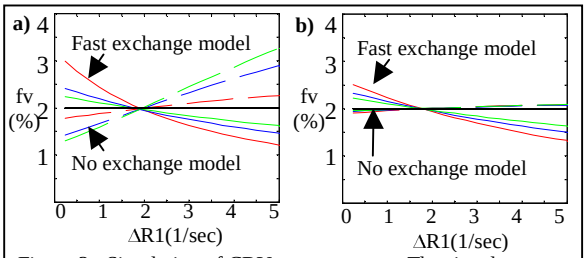

Figure 3 : Simulation of CBV measurement. The signal intensities with different water exchange rates (red=1, blue=5, and green=10/s) were simulated. Solid line is based on fast exchange model, and dash line is based on no exchange model. a) normal methods b) EM-IR methods

Results

T1 measurement of water phantoms has 3% of error (overestimated, not shown) and T1 measurement of brain show the good correlation (R = 0.9578). The simulation result (figure3) shows that nEM-IR method is less sensitive to water exchange rate than fEM-IR method. fEM-IR method is still dependent on water exchange rate while fEM-IR method (fitting up to the null point) is less sensitive to water exchange rate than normal method (fitting the whole curve). In volunteer study, $qCBV_{SS}$ values from fEM-IR true FISP are 1.33 ± 0.32 and 2.19 ± 0.47 (ml/100g) and $qCBV_{SS}$ values from nEM-IR true FISP are 2.47 ± 0.26 and 4.22 ± 0.14 (ml/100g) in white and gray matter respectively.

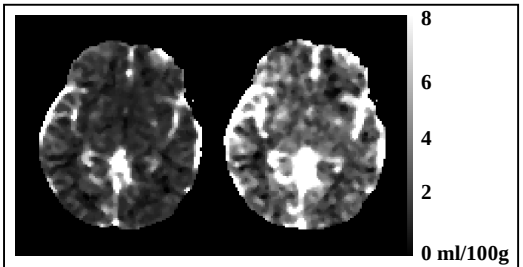

Figure 4 : qCBVss maps a) fEM-IR true FISP method b) nEM-IR true FISP method

Conclusion

We present water exchange minimized qCBV measurement using IR true FISP based on both fast and no water exchange model. For fEM-IR true FISP, T1 values were measured using IR true FISP by fitting up to the null point, and compared with true T1 values. IR true FISP produced T1 values with a high accuracy. From the simulation results, fEM and nEM-IR true FISP method were used to measure $qCBV_{SS}$ in WM and GM. qCBVss values using nEM-IR true FISP is closer to the published values (2.2ml/100g for WM, 4ml/100g for GM) than fEM-IR true FISP method. qCBVss values using fEM-IR true FISP were underestimated, which corresponds to the simulation result at ΔR=3.44/sec (table 1).

Table 1 : qCBV values from EM-IR methods

Volunteer	qCBV (ml/100g)				ΔR1(1/s)
	fEM-IR FISP		nEM-IR FISP		
	WM	GM	WM	GM	
mean	1.32556	2.19178	2.47266	4.22434	2.124804
std	0.321787	0.473734	0.263559	0.147011	1.870261

Reference

1. Speck et al., *MRM*, 1999;41:1264-1268 2. Lin et al., *JMRM*, 1999;9:44-52 3. Donahue et al., *MRM*, 1996;36:858-867 4. Scheffler K., *MRM*, 2003;49:781-2003 5. Chung et al., *MRM*, 2002;10;1283