Estimation of brain perfusion using flow-compensated intravoxel incoherence motion MRI: a simulation study

Yen-Peng Liao[1], Shin-ichi Urayama[1], and Hidenao Fukuyama[1]

[1]*Human Brain Research Center, Kyoto University, Kyoto, Japan*

Introduction

The intravoxel Incoherence Motion (IVIM) model can be used for not only correction of flow contamination in diffusion-weighted imaging (DWI), but also for the estimation of the perfusion relative indices in tissues. This method has been widely applied in various organs as a surrogate marker. However, due to the relative small blood volume weighting in the brain, the cerebral IVIM effect is small. That is, much higher signal-to-noise ratio (SNR) is required to estimate perfusion with the IVIM model in brain (1). Therefore, it is challenging to estimate accurate and precise brain hypoperfusion. Some studies showed that flow-compensated pulse might be useful to suppress the contamination of the IVIM effect (2). This study proposed a strategy to estimate hypoperfusion in brain with the combination of conventional DWI and flow-compensated DWI. Computer simulation was performed to evaluate the feasibility of the proposed method.

Methods and Materials

The general IVIM model can be described as:

$$\frac{S(b)}{S(0)} = (1-f)e^{-bD_t} + fe^{-b(D_b+D^*)} \quad [1]$$

, where signal, *S,* is a function of *b*-value, *f* is the perfusion fraction, *D** is the pseudodiffusion coefficient, D_t and D_b are the diffusion coefficient of tissue and blood, respectively. In small *b*-value condition, we can simplify the model as:

$$\frac{S(b)}{S(0)} = (1-f)(1-bD_t) + f(1-bD_b - bD^*) \quad [2]$$

, and the flow-compensated signal, S_{FC}, can be described as:

$$\frac{S_{FC}(b)}{S(0)} = (1-f)(1-bD_t) + f(1-bD_b) \quad [3].$$

Then, we can derive the blood flow relative parameter, *fD**, with :

$$fD^* = \frac{S_{FC}(b) - S(b)}{bS(0)} \quad [4].$$

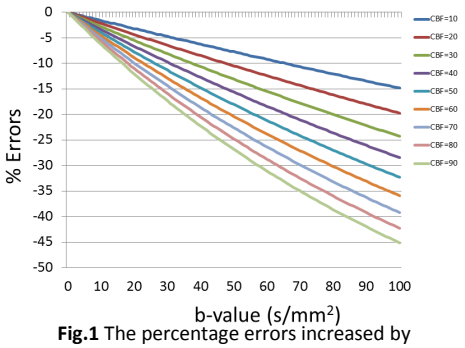

Fig.1 The percentage errors increased by increasing *b*-values and increasing CBF (mL/100g/min) while CBV=5 mL/100g.

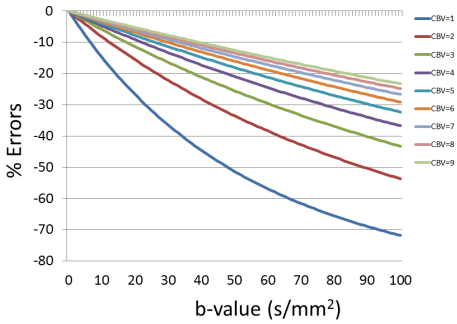

Fig.2 The percentage errors increased by increasing *b*-values and decreasing CBV (mL/100g) while CBF=50 mL/100g/min.

Table 1 %ME and %COV in estimations of *fD** with fixed CBV and varied CBF in SNR=300.

CBV= 5 mL/100g	Biexponential Fitting		Proposed Mothod	
CBF(mL/100g/min)	%ME	%COV	%ME	%COV
10	5.4	104.7	-7.4	52.5
20	3.4	18.4	-6.1	26.6
30	3.1	12.2	-9.3	16.5
40	1.9	10.6	-11.3	13.9
50	1.4	9.9	-13.6	11.0
60	1.6	10.2	-14.8	10.0
70	1.8	10.7	-16.6	8.9
80	1.6	11.3	-17.9	7.8
90	1.7	11.9	-19.7	6.9

Table 2 %ME and %COV in estimations of *fD** with fixed CBF and varied CBV in SNR=300.

CBF= 50 mL/100g/min	Biexponential Fitting		Proposed Method	
CBV(mL/100g)	%ME	%COV	%ME	%COV
1	54.5	153.8	-40.9	16.8
2	5.8	30.7	-25.5	13.5
3	3.3	19.8	-18.6	12.3
4	2.2	13.7	-15.1	11.9
5	1.4	9.9	-13.6	11.0
6	1.3	8.1	-11.3	11.2
7	1.2	6.9	-10.6	11.2
8	1.2	6.1	-9.9	10.8
9	1.1	5.7	-9.0	11.1

The tissue signal curves were simulated using Eq. [1] with Rician noise of SNR=300 which is the least requirement for IVIM study of brain (3). The heterogeneity of tissue was simulated by varying cerebral blood flow (CBF) from 10 to 90 mL/100g/min and cerebral blood volume (CBV) form 1 to 9 mL/100g. The values of *f* and *D** were based on the theory demonstrated by Le Bihan and Turner (4). Both the bi-exponential model fitting (Eq. [1]) and the proposed method (Eq. [4]) were used to estimate *fD**. The *b*-value = 0, 40, 150, 160, 170, 180, 190, 250, 260, 440, 560, 580, 700, 710, 860, 980, 1000 s/ mm^2, and 0 to 100, step by 1 mm^2/s was set for the fitting methods. For the proposed method, 0 - 100 s/mm^2 of *b*-values were test to find the optimal one which showed minimum errors. One thousand repeats of each condition were performed, and the percentage mean error (%ME) and the coefficient of variation (%COV) were calculated.

Results

Figure 1 showed that the percentage errors increased by increasing *b*-values and increasing CBF. Figure 2 showed that the percentage errors increased by increasing *b*-values and decreasing CBF. To minimize the errors to less than 5%, generally, the *b*-value=10 s/mm^2 should be set. In the condition of SNR=300, Table 1 and Table 2 demonstrated the %ME and %COV in estimations of *fD** using bi-exponential model fitting and the proposed method (b-value=35). The biexponential fitting showed overestimation while the proposed method showed underestimation due to the systematic errors. The %COV can be improved by increasing CBF and CBV.

Discussion

This study proposed a method to estimate the CBF related parameter, *fD**, in hypoperfusion conditions. Compared with the biexponential fitting, the proposed method provide less %COV with similar %ME in extremely low CBF and CBV conditions. This indicated that the proposed method might useful in estimation of hypoperfusion with an appropriate *b*-value. However, in hyperperfusion and small blood volume conditions, this method may be limited to use small b-values. Therefore, high SNR will be required. Future work will be to verify this method in vivo.

References

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