Variability of model-based blood volume correction and vessel permeability estimation in dynamic susceptibility contrast MRI: A computer simulation study

L-W. Hsu[1], Y-P. Liao[1], and H-L. Liu[1,2]
[1]Institute of Medical Physics and Imaging Science, Chang Gung University, Taoyuan, Taiwan, [2]Department of Medical Imaging and Intervention, Chang Gung Memorial Hospital, Taoyuan, Taiwan

Introduction: Dynamic susceptibility contrast (DSC) MRI is a noninvasive tool for diagnosis and treatment evaluation of brain tumors [1]. One of the assumptions in DSC-analysis is based on an intact blood-brain barrier (BBB). However, when BBB is disrupted, contrast agent can leak into extravascular space and result in errors in the estimation of tumor blood volumes (BV). Mathematical models have been developed to correct for T_1 and T_2 effects originated from the contrast agent extravasations [2, 3], and showed additional potentials for assessing vessel permeability. This study aimed to assess the variability of BV corrections as well as quantification of vessel permeability, based on the model, that attribute to noises in the data. Baseline longitudinal relaxation rates (R_{10}) were simulated as both a variable in data fitting or fixed values from measurements.

Methods: A two-compartmental model was used to correct the combined T_1 and T_2 effects due to contrast agent leakage in the measured DSC-MRI signals [3]:

$$\Delta \tilde{R}_2^*(t) \equiv -\frac{\ln(S(t)/S(0))}{TE} \equiv K_1 \cdot \overline{\Delta R_2^*}(t) + \frac{PS}{V_p} \cdot \int_0^t \overline{\Delta R_2^*}(t')dt' - \frac{1}{TE} \cdot \ln\left(\frac{1 - e^{-TR \cdot \left(R_{10} + \frac{r_1}{r_2^*} \cdot \frac{PS}{V_p} \cdot \int \overline{\Delta R_2^*}(t')dt'\right)}}{1 - e^{-TR \cdot R_{10}}}\right) \quad [1]$$

where S_0 is the baseline signal, K_1 is a proportional contrast, $\overline{\Delta R_2^*}(t)$ is an averaged effective transverse rate change time curve ($\Delta R_2^*(t)$) without leakage, as obtained from normal tissue, $\Delta \tilde{R}_2^*(t)$ is the measured $\Delta R_2^*(t)$ from a tumor voxel, r_1 is the longitudinal relativity of contrast agent, r_2* is the effective transverse relativity of contrast agent, and V_p is the blood volume of the normal reference tissue. TR and TE are the repetition time and the echo time of MRI sequence parameters. Three unknown parameters, K_1, R_{10}, and PS/V_p, can be obtained from a least-square fitting, and used to calculate corrected BV. When R_{10} is measured, unknown parameters are reduced to two and better fitting is expected. Monte Carlo simulation was applied to add different noise levels (Gaussian noise with SNR=10, 50 and 100) to the tumor signal time curves with 1000 iterations each. Concentration time curves with three different levels of vessel permeability (permeability surface-area product, PS, = 0.0006, 0.001 and 0.003) were generated using the following equation before they were converted into tumor signal time curves:

$$\Delta R_{1,E}(t) = \frac{PS}{V_p} \cdot \frac{r_1}{r_2^*} \cdot \int_0^t \Delta \overline{R}_2^*(t')dt' \qquad \Delta R_{2,E}^*(t) = \frac{PS}{V_p} \cdot \int_0^t \Delta \overline{R}_2^*(t')dt'$$

Eq.[1] was applied for fitting the simulated tumor time curves. Mean error and coefficient of variance (CV) of PS/V_p and corrected BV were calculated for each permeability and SNR condition.

Results: Fig. 1 shows that measuring R_{10} can reduce the mean error and variation of corrected BVs in all conditions, especially for high permeability and low SNR When vessel leakage is minor (Fig. 1(a)), mean errors was less than 5% even without measuring R_{10}. Similarly, Fig. 2 shows that measuring R_{10} can reduce the mean error and variation of PS/V_p estimations in all conditions. Percent errors of the PS/V_p were greater when the target values were either large or small. When R_{10} is provided, mean errors of PS/V_p estimates were less than 5% in all cases.

Conclusion: Our computer simulations showed that quality of model-based BV correction and permeability estimation depended on both SNR and severity of contrast agent leakage in DSC-MRI. Accurate measurement of baseline T_1 is especially helpful for the situation of high vessel permeability and low SNR acquisition.

Fig. 1 The mean error and CV of rCBV

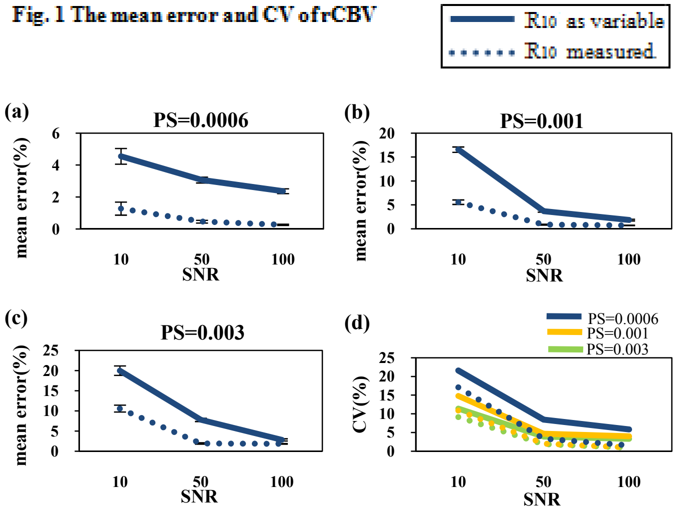
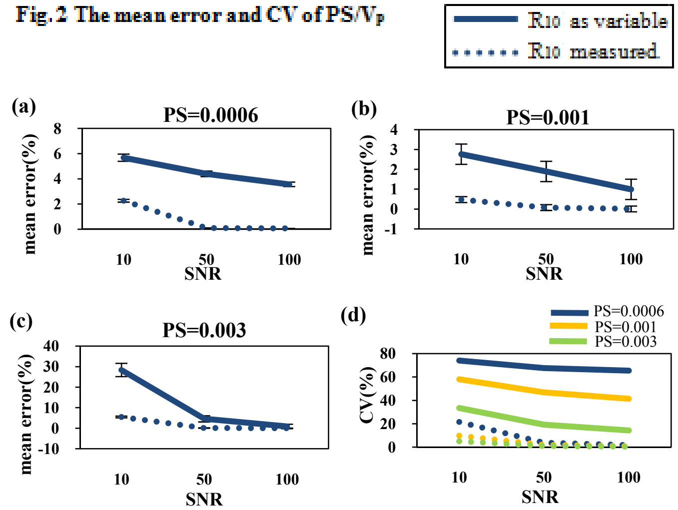


Fig. 2 The mean error and CV of PS/Vp



References: 1. J.L. Boxerman et al, AJNR, 2006 **2.** R.M. Weisskoff et al, Soc. MRM, 1994 **3.** Y.Y. Wu et al, ISMRM, 2009