Quantification of Vessel Permeability with Dynamic Susceptibility Contrast MRI

Y-P. Liao[1], Y-Y. Wu[2], Y-Y. Hsu[3], Y-Y. Wai[1,4], and H-L. Liu[1,4]

[1]Department of Medical Imaging and Radiological Sciences, Chang Gung University, Taoyuan, Taiwan, [2]Department of Radiology, Taichung Veterans General Hospital, Taiwan, [3]Department of Medical Imaging, Buddhist Tzu Chi General Hospital, Taipei, Taiwan, [4]Division of Medical Imaging and Intervention, Chang Gung Memorial Hospital, Taoyuan, Taiwan

Introduction

In dynamic susceptibility contrast MRI (DSC-MRI), T_2*-weighted signals may be contaminated by contrast agent leaking out of the vasculature into the extravascular extracellular space (EES) when brain-blood-barrier (BBB) is disrupted, e.g. brain tumor cases. The phenomenon results in both additional T_1 and T_2* relaxation effects which influence the difference of T_2* relaxation rate (ΔR^*_2). Previous studies model DSC-MRI signals considered T_1, T_2, and T_2* effect with the leakage effect (1, 2, 3). This study aimed to quantify the permeability surface area product (PS) with an individual-estimated T_1 map. The corrected relative cerebral blood volume (rCBV) was estimated at the same time.

Methods

The Weisskoff model expressed the estimated $\Delta R^*_{2,\text{uncorr}}$ contaminated by leakage effect in DSC-MRI(1):

$$\Delta R_{2,uncorr}^{*}(t) = K_1 \cdot \Delta \bar{R}_2^{*}(t) - K_2 \cdot \int_0^t \Delta \bar{R}_2^{*}(T) \cdot dT \quad , \qquad [1]$$

where $\Delta \bar{R}^*_2(t)$ is the estimate of $\Delta R_2^*(t)$ without leakage, obtained from averaged $\Delta R_2^*(t)$ of healthy tissues, K_1 and K_2 are constants. Our previous study presented a model including T_1 and T_2* effect (3). Therefore K_2 can be described as a constant implicating PS:

$$K_2 = \frac{PS}{v_P}\left(\frac{T_R}{T_E}\cdot\frac{E_1}{1-E_1}\cdot\frac{r_1}{r_2^*}-1\right) \qquad [2]$$

, where E_1=exp(-T_R/T_{10}), v_P is the fraction of plasma in normal tissues, T_{10} is estimated T_1 before injection and r_1/r_2* are the ratio of longitudinal/transverse relaxivities, respectively. In addition, the corrected relative $\Delta R^*_{2,\text{corr}}$ can be calculated by the equation:

$$\Delta R_{2,corr}^{*}(t) = \Delta R^{*}_{2,uncorr}(t) + K_2 \cdot \int_0^t \Delta \bar{R}_2^{*}(T) \cdot dT \qquad [3]$$

Then the corrected rCBV was calculated with the estimated K_2. One clinical subject with brain tumors participated in the study with informed consent. Before contrast agent injection, the multi-T_1 single shot gradient echo EPI images were acquired fot T_1-mapping with T_1 = 400, 800, 1200, 1600, and 2000 ms, TR/TE = 10000/19.9 ms, and NEX=1. T_2*-weighted gradient-echo EPI sequence (T_R/T_E/FA=1500 ms/ 35 ms/90°) was applied for the DSC-MRI at a 3T clinical scanner. A dose of 0.1 mmol/kg of Gd-DTPA was injected at a rate of 4 ml/s through the antecubital vein for the DSC imaging. The post-contrast T_1-weighted images were acquired after DSC MRI acquisition. For the DSC images, slice timing correction was first performed by using SPM2 software. All data were analyzed with a homemade program based on Matlab 7.0.

Results

In Fig.1, the PS map (Fig.1a) and the post-contrast T1-weighted image (Fig.1b) of the patient are presented. The averaged PS for tumor (0.127 min^{-1}) was significantly larger than the white matter (0.004 min^{-1}). In Fig. 2, the rCBV maps are shown. The uncorrected rCBV presented here is shown to be overestimated as the previous study (3). The ratio of uncorrected and corrected rCBVs in gray matter and white matter were 2.0 and 1.6, respectively.

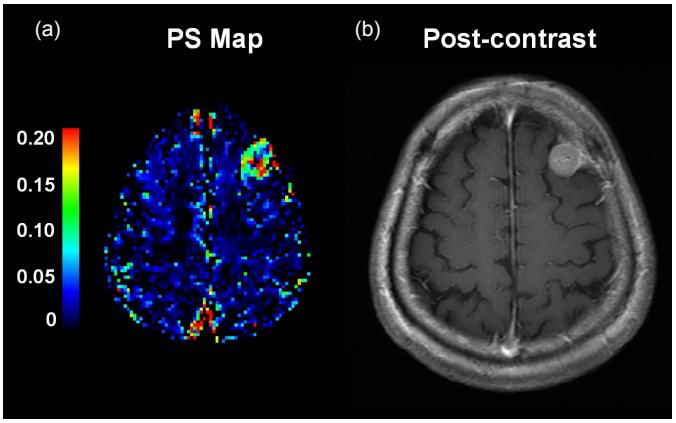

Fig.1. The PS map (a) and T1-weighted image (b).

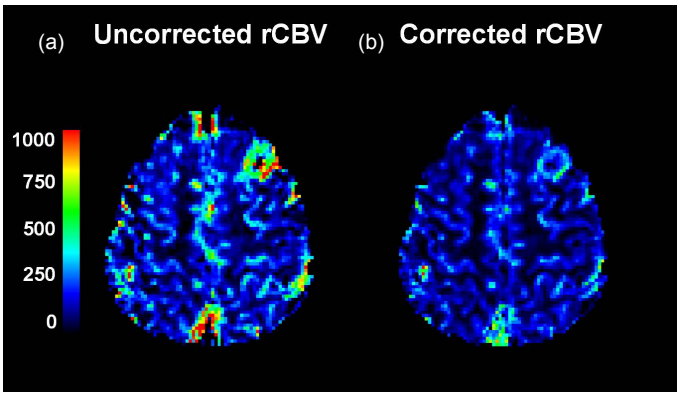

Fig.2. The uncorrected rCBV map (a) and the corrected rCBV map (b)

Conclusion

In this study, we presented a method to absolutely quantify PS. The T_1 of pre-contrast tissue were required in the PS estimation. The values of PS were comparable to those in literatures. Future work will include more patients to verify this method.

References

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