Effects of Pre-loading Dose on DSC-MRI with Contrast Agent Extravasation

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Introduction

In dynamic susceptibility contrast (DSC) MRI, disruption of the BBB in brain lesions frequently interferes in accurate quantification of regional perfusion because leakage of contrast agents from the vasculatures into the extravascular extracellular space (EES) would significantly alter local T1 and T2 relaxation effects. Though pre-loading method has been commonly applied for attenuating the additional T1 effects in brain lesions with BBB disruption (1, 2), there is lack effective studies to evaluate how the pre-loading dose affect the relative cerebral blood volume (rCBV) measurement. In this study, we proposed a simulation model to investigate the quantification of rCBV with various pre-loading dose at 1.5T and 3.0T magnetic fields.

Methods

In the DSC-MRI, the exhibition of the combined T_1 and T_2 effects resulted from the contrast passage is expected to vary with baseline relaxation rates and relaxivity (which depends on field strength) and imaging parameters. In a DSC study, standard tracer kinetics gives the relationship:

$$C_V(t) = F_P \cdot C_{P,A}(t) \otimes R(t)$$

where $C_V(t)$ is the concentration of contrast agent in an imaging volume, F_P is the blood flow, $C_{P,A}(t)$ is the arterial input function and R(t) is the vascular residue function. For this simulation, F_P was assumed to be 0.01 ml/g/s and $C_{P,A}(t)$ was modeled using a gamma variate function to approximately match typical clinical data. Then we separated the intra- and extra-vascular components of R(t), into $R_P(t)$ and $R_E(t)$, respectively (3):

$$R_P(t) = e^{-t/MTT}$$
$$R_E(t) = E \cdot \left(1 - e^{-t/\mathrm{MTT}}\right)$$

where MTT was mean transient time and E was the exchange fraction. Three different leakage conditions were included by setting E = 0 (no leakage), 0.05, 0.1, and 0.15, and MTT was given as 4 seconds. To generate DSC-MRI time curves with pre-loading dose, the followings were substituted into signal equation with contrast agent extravasation:

$$\Delta R^*_{2,p}(t) = r^*_2 \cdot \left(F_P \cdot C_{P,A}(t) \otimes R_p(t)\right)$$
$$\Delta R^*_{2,E}(t) = r^*_2 \cdot \left[\left(F_P \cdot C_{P,A}(t) \otimes R_E(t)\right) + C_{pre}\right]$$
$$\Delta R_{1,E}(t) = r_1 \cdot \left[\left(F_P \cdot C_{P,A}(t) \otimes R_E(t)\right) + C_{pre}\right]$$

where r_1 and r_2^* was set as 3.9 and 44 L/s . mmol, respectively for 1.5 T, and 3.3 and 87 L/s . mmol, respectively for 3 T. And C_{pre} was concentration of pre-loading dose in EES. The signal intensity time curve, S(t) can be approximated as:

$$S(t) = M_0 \cdot \left\{1 - e^{-\left[TR \cdot (R_{10} + \Delta R_{1,E}(t))\right]}\right\} \cdot e^{-\left\{TE \cdot \left[R^*_{20} + \Delta R^*_{2,P}(t) + \Delta R^*_{2,E}(t)\right]\right\}}$$

where TR=1500 ms, and relaxation rates were set as R_{10} = 0.67/0.50 s^{-1} and R_{20}^* = 25/29 s^{-1} for 1.5/3 T in this simulation, as commonly found in brain tumors (3). Two TEs, 30 and 50 ms, were included in the simulation to generate different T_2^*-weighting.

Here we using the model to calculate signal time curves to simulate the effects using different TEs at both 1.5 T and 3 T, with different level of contrast agent extravasation. And we calculated the rCBV error with different concentrations of pre-loading dose in each condition.

Results

When rCBV underestimation the error will be negative and overestimation will be positive. From our simulations results (Figure 1, 2), the rCBV were commonly underestimated at 1.5 T without pre-loading dose or with low pre-loading dose, but it overestimate when TE was longer at 3 T. However, when the different amount pre-loading dose applied to each condition, the underestimation was improved with larger pre-loading dose. But when pre-loading has overdosed into the data, overestimation will happen.

Conclusion

The proposed model was able to simulate DSC signal time curves measured at 1.5 T and 3 T with pre-loading dose in brain tumor. In conclusion, this experiment provided important evidence that how the pre-loading dose affect the accurate quantification of rCBV measurement.

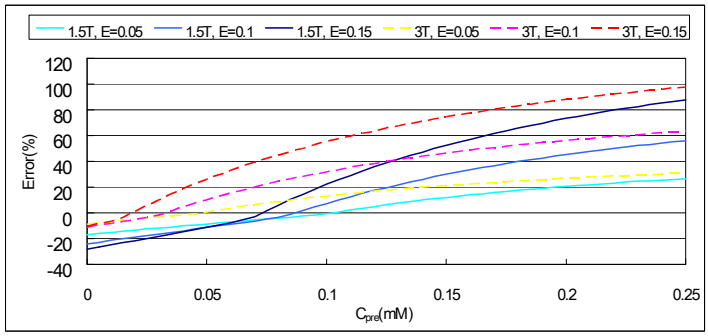

Figure 1. In TE set as 30, percent rCBV errors in different leaky conditions, when different pre-loading dose factors were given at 1.5 T and 3 T.

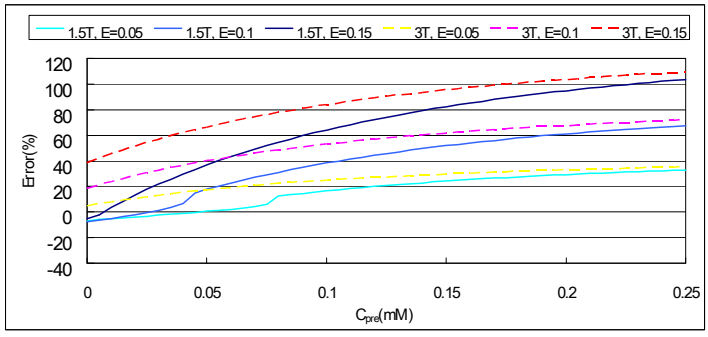

Figure 2. In TE set as 50, percent rCBV errors in different leaky conditions, when different pre-loading dose factors are given at 1.5 T and 3 T.

References

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