Contrast agent extravasation correction combined with automated AIF identification in DSC-MRI

Q. Ji[1], J. O. Glass[1], and W. E. Reddick[1]

[1]Radiological Science, St.Jude Children's Research Hospital, Memphis, TN, United States

INTRODUCTION: Dynamic-susceptibility contrast perfusion MRI (DSC-MRI) is generally used to access the cerebral microcirculation. Since the blood-brain-barrier (BBB) strictly confines the blood in the vascular space, only vascular tissue can be enhanced when the contrast agent passes through the brain in DSC-MRI scans. Important quantitative parameters can be estimated by tracking the bolus of the contrast agent. When the BBB is damaged or broken down, which is usually occurred in the many cerebral diseases, the blood is no longer confined to the vascular space. The leakage of contrast agent in DSC-MRI can cause under or over estimation of cerebral blood volume measurements because the method of bolus tracking is no longer accurate. The purpose of this study was to develop a method to correct the leakage in DSC-MRI. The leakage of contrast agent can cause two effects to the measured T2* images. The first effect is a T1 enhancement effect which is a positive enhancement in intensity. The second effect is a T2* effect in the extra-vascular space which differs from the one in the vascular space. Both effects can contaminate the relaxation-time course. The dynamic behavior of the contrast agent transferred from vascular to extra-vascular space has been well described by the pharmacokinetic model in dynamic contrast enhanced (DCE) MRI studies [3]. Based on the pharmacokinetic model, we suggest a general correction method which can correct both T1 and T2* effects due to the contrast agent leakage in DSC-MRI. Different from many previous studies [1,2], we used measured arterial input function (AIF) from the DSC-MRI itself [4] and then applied it in the correction model. The advantage of using a measured AIF is that it is best adapted to individual vascular touristy, and no extra parameters need be introduced in the model. T2* weighted image data sets from fifteen pediatric brain tumor patients have been evaluated with this method.

METHODS: The pharmacokinetic model used to describe the brain DSC-MRI time-course is:

$$C_t(t) = v_p C_p(t) + k_{leak} \int_0^t C_p(t-\tau)\, d\tau$$

where $C_t(t)$ and $C_p(t)$ are the concentrations of contrast agent in tissue and plasma respectively, v_p is volume fraction of blood plasma on each image pixel and k_{leak} is the correction coefficient which has units of min^{-1} and can be positive or negative depending on the type of leakage enhancement. k_{leak} reflects the offset caused by T1 and T2* effects induced by contrast agent in the extra-vascular space. In the derivation of the model equation, we ignored the potential effect of contrast agent transport back to the blood plasma because the transfer constant of BBB is usually very small. $C_p(t)$ is the arterial input function (AIF) and can be measured from each imaging set using an algorithm called iterative self-organizing map (SOM) clustering method [4]. Fifteen pediatric patients treated for high grade glioma were imaged using T2* weighted perfusion MRI as part of the routine clinical assessment. The patients' perfusion MRI data was first converted from intensity-time series to concentration-time series, and then the AIF was obtained. Before fitting the model with each pixel's time-course, an automatic procedure that aligns the AIF and pixel data was applied. The fitting of the model with the pixel concentration time course was optimized by a linear fitting algorithm.

RESULTS: Analysis of the fifteen patient data sets revealed that most pixels were fitted very well by the model (chi-squares are below the fitting threshold). Very noisy and non-enhancing regions such as CSF did not fit as well. The model fit of three typical concentration-time courses: (a) with T2* effect, (b) with T1 effect and (c) with little or no leakage is illustrated in **Fig. 1.** Typical fitted v_p and k_{leak} maps are demonstrated in **Fig. 2** along with the un-enhanced T2* weighted image. There were three interesting findings shown in this example: (1) the contrast agent leakage due to the recurrence of tumor can be seen on fitted k_{leak} maps (as shown by the green spot in the far right image), (2) in the leakage region, both T1 and T2* effects are present and (3) some "leakage" was demonstrated at the tissue-CSF boundary. Even though the T2* effect was dominate in our pediatric brain tumor patients, the fitted k_{leak} can not be considered an accurate measurement of the BBB permeability because T1 and T2* effects are in opposing directions.

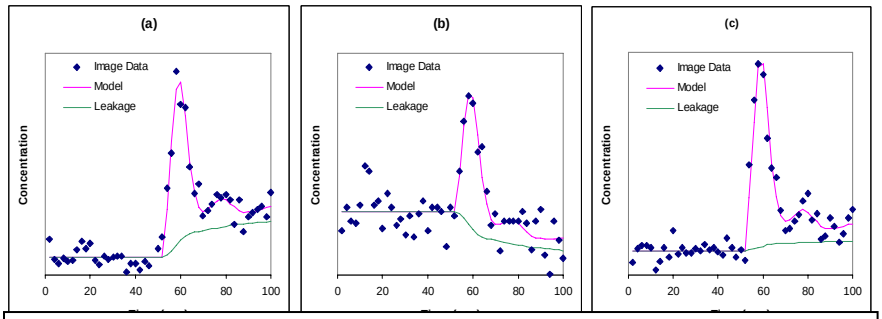

Fig. 1 Fitted Concentration-Time Course. (a) k_{leak} = 0.082 (min^{-1}), v_p = 0.204, (b) k_{leak} = -0.02 (min^{-1}), v_p = 0.07, (c) k_{leak} = 0.002(min^{-1}), v_p = 0.168

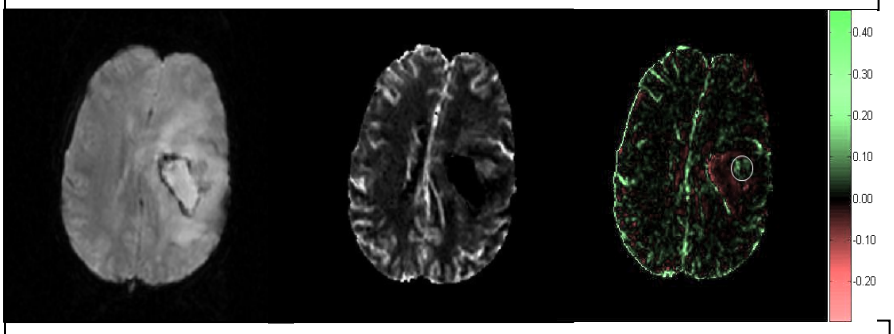

Fig. 2 Fitted Parameter Maps. From left to right: un-enhanced T2* Image, v_p map, and k_{leak} map in which the leakage spots have been circled.

DISCUSSIONS AND CONCLUSION: We have demonstrated a contrast agent leakage correction method for T2* weighted DSC perfusion MRI. The measured perfusion data was fit by the correction model very well for the fifteen patients assessed. Incorporation of this leakage model easily corrected the concentration-time course to avoid over or under estimation of blood volume and flow.

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