Study of Injection Duration and Onset Time Uncertainty in Dynamic Contrast Enhanced MRI: A Comparison of a Reference Region Model with a Simple 2-compartment Kety Model

Y-P. Liao[1], I-T. Hsiao[1,2], and H-L. Liu[1,2]

[1]Institute of Medical Physics and Imaging Science, Chang Gung University, Tao-Yuan, Taiwan, [2]Department of Medical Imaging and Radiological Science, Chang Gung University, Tao-Yuan, Taiwan

Introduction

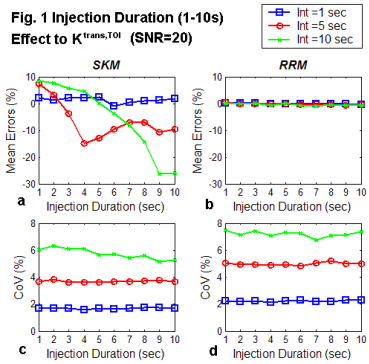
An arterial input function (AIF) is essential for T1-weighted dynamic contrast-enhanced (DCE) MRI with traditional tracer kinetic analysis. The goal of DCE-MRI is to estimate the physiological parameters such as K^{trans} and v_e in target of interest (TOI). To improve the temporal resolution for AIF sampling, a fast imaging sequence is needed [Ref.1]. However, high temporal resolution often accompanies lower spatial resolution and SNR, and that may cause partial volume effect, and thus image degradation. A 2-parameter-fit reference region model (RRM) was introduced [Ref.2] to avoid AIF sampling under the condition that a reference region (RR) tissue with stable $K^{trans,RR}$ (volume transfer constant of RR) and $v_{e,RR}$ (extravascular extracellular space volume of RR) is available. In the 2-parameter-fit RRM, $K^{trans,TOI}$ (volume transfer constant of TOI) and $v_{e,TOI}$ (extravascular extracellular space volume of TOI) is estimated with fixed $K^{trans,RR}$, $v_{e,RR}$, and a smoothed concentration of a reference region (C_{RR}). This study is aimed to evaluate the influence of temporal resolution and AIF shape on DCE-MRI data analysis with a 2-parameter-fit RR model. The performance of RR model (RRM) is compared with simple two-compartment Kety model (SKM) with sampled AIF.

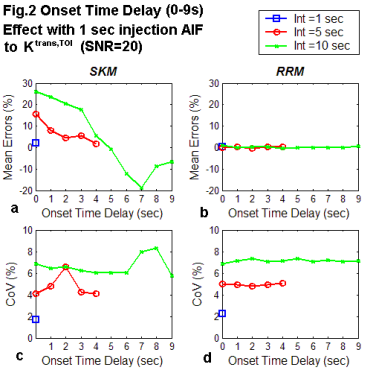
Methods

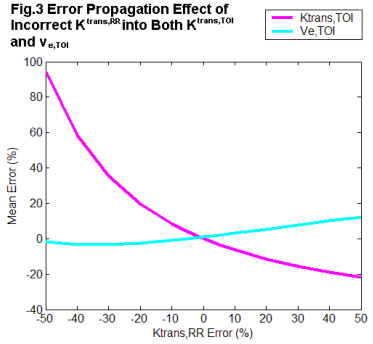
The AIF data from a previous study by Yankeelov, et al. [Ref.3] were re-sampled and interpolated to 1 second temporal resolution as $C_{p,bolus}(t)$. To simulate a slow injection, a dispersed AIF, $C_{p,disp}(t)$, was generated by a convolution of $C_{p,bolus}(t)$ with a rectangular function Π(t) as: $C_{p,disp}(t) = C_{p,bolus}(t) * \frac{1}{t_{inj}} \Pi\left(\frac{t}{t_{inj}}\right)$, where t_{inj} describes the injection duration and * denotes a convolution operation. In the injection duration tests, clinical conditions of contrast agent injection time from 1 to 10 seconds without onset time errors were simulated; in the onset time tests, the delay time was set from 0 to 9 seconds with 1 second injection AIF, and the initial condition of onset time was set in half of sampling interval (no delay considered in 1 second sampling interval). The concentration of target of interest (C_{TOI}) and reference region (C_{RR}) were simulated by a simple two-compartment tracer kinetic model. The true physiological parameters were set with $K^{trans,TOI}$=0.25(min^{-1}), $v_{e,TOI}$ =0.45, $K^{trans,RR}$=0.1(min^{-1}), and $v_{e,RR}$=0.08 in the tracer kinetic model. 1000 trials with SNR=20 and SNR=50 and noise free conditions were simulated. Then the $K^{trans,TOI}$ and $v_{e,TOI}$ were estimated using both the Kety model with sampled AIF, and the 2-parameter-fit RR model with a known $K^{trans,RR}$=0.1(min^{-1}) and a fixed $v_{e,RR}$ = 0.08. The AIF used in Kety model was fitted by a bi-exponential model [Ref.4]; the C_{RR} used in RR model was fitted by a bi-gamma-variate function. In addition, error propagation from incorrect $K^{trans,RR}$ into both $K^{trans,TOI}$ and $v_{e,TOI}$ in 2-parameter-fit RR model were also studied. The "lsqcurvefit" program in Matlab optimization toolbox was used for least-square-curve- fitting in all conditions.

Results

Fig.1 shows the influence of different AIF shapes on estimating $K^{trans,TOI}$ in both SKM and 2-parameter-fit RRM. In a sampling interval of 5 seconds, the mean errors of $K^{trans,TOI}$ are about -14.88% to +7.4% with different injection duration from 1 to 10 seconds in SKM (Fig. 1a), while the 2-parameter-fit RRM produced results with mean errors less than 1 % (Fig.1b). Fig. 2 illustrates the temporal resolution effect in estimating $K^{trans,TOI}$ with 1 second injection duration. The estimated $K^{trans,TOI}$ from SKM displays +1.6% to +15.64% mean errors (Fig.2 a) but less than 1 % mean errors were shown from the 2-parameter-fit RRM (Fig2 b). The coefficient of variation (CoV) is defined as standard deviation divided by mean value. The RRM (Fig.1 d and Fig. 2 d) shows similar or a somewhat higher CoV to that by SKM (Fig.1 c, Fig.2 c) with SNR=20. Fig. 3 illustrates the error propagation effect from $K^{trans,RR}$ into both $K^{trans,TOI}$ and $v_{e,TOI}$ in the 2-parameter-fit RRM. An incorrect $K^{trans,RR}$ with errors varying from -11.6 % to 18.3% causes about ±10 % errors in $K^{trans,TOI}$ estimation.







Discussions

In this study, the performance of RRM with different sampling intervals and CA injection durations was studied. Compared with the traditional DCE-MRI analysis with sampled AIF, RRM shows stable and smaller mean errors and similar CoV of $K^{trans,TOI}$ estimations in both lower temporal resolution and varying injection durations. However, the accuracy of $K^{trans,RR}$ might influence the final estimation of $K^{trans,TOI}$ and $v_{e,TOI}$ in the RRM method. This study assumed same AIF for both tumor and reference regions. For future work, we will also consider the effect of different AIFs on both tumor and reference regions.

References

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