Impact of AIF Errors on DCE-MRI Pharmacokinetic Parameters: Comparison of a High Temporal Resolution AIF and a Biexponential Description

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INTRODUCTION

A necessary but difficult requirement for quantitative dynamic contrast-enhanced (DCE) MRI is measurement of the arterial input function (AIF) [1]. Ideally, individual AIFs should be acquired and with a high temporal resolution (1 s [2]) to capture rapid changes during the initial bolus passage, which is believed to be essential for reliable DCE-MRI [3]. However, this approach places stringent demands on temporal resolution, and errors due to partial volume, saturation, and inflow will be more severe during the bolus phase [4,5]. The touted advantages of a rapidly acquired AIF have not been investigated when errors exist in its measurement. The purpose of this work was to study the impact of AIF errors on DCE-MRI parameter accuracy and to compare a high temporal resolution AIF versus the common alternative of a more slowly but carefully acquired biexponential decay description.

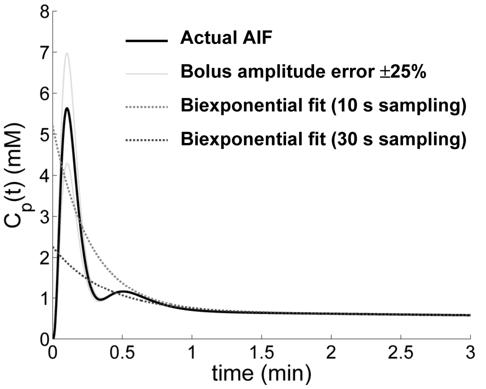

Fig. 1. Actual AIF was used in data generation. For model fitting, AIF assumed either a bolus amplitude error for rapid sampling (1 s) or was fitted to a biexponential function for low temporal resolution data (5-30 s).

METHODS

Data generation began by simulating an AIF similar in form to that measured experimentally in patients [6] (Fig.1). The AATH model [7] was then used to generate tissue time-courses for a range of parameter values: K^{trans}=0.01-1 min^{-1}, v_p=0.01-0.2, v_e=0.1-0.4. The datasets were down-sampled for different temporal resolutions (1-30 s), prior to which blood and tissue curves were shifted by fractions of the sampling interval in steps of 1 s to simulate temporal jitter [2].
Tissue curves were then fitted to Eq.[1] for two scenarios: (1) high temporal resolution (1 s), where the AIF bolus amplitude was assumed to be in error and was varied between 0.5 and 2 times the amplitude used in data generation; (2) low temporal resolutions (5-30s), where the AIF was fitted to a biexponential function prior to model fitting. Fit results from all parameter ranges were averaged to yield median parameter estimates.

$$C_t(t) = v_p C_p(t-t_o) + K^{trans} \int_0^{t-t_o} C_p(\tau) \exp\left(\frac{-K^{trans}}{v_e}(t-\tau-t_o)\right) d\tau \qquad [1]$$

RESULTS

Fig.1 shows the true AIF used in data generation and actual AIFs used in model fitting. Fig.2 illustrates parameter estimation when temporal resolution is high (1 s) but the AIF bolus peak amplitude is incorrectly measured. Both K^{trans} and v_p exhibit substantial error that is roughly inversely proportional to the relative AIF bolus amplitude error. Fig.3 illustrates parameter estimation at low temporal resolutions (≥ 5 s). Parameter v_p is not show, as it is generally poorly estimated under the biexponential AIF assumption. Parameter K^{trans} is seen to be surprisingly robust to slow sampling, with an underestimation generally within 20%. Deviations from this pattern occur only for sampling slower than every 20 s or for very small K^{trans} (<0.1 min^{-1}). Parameter v_e is the most robust, varying mostly within 10% of its true value for v_e>0.1.

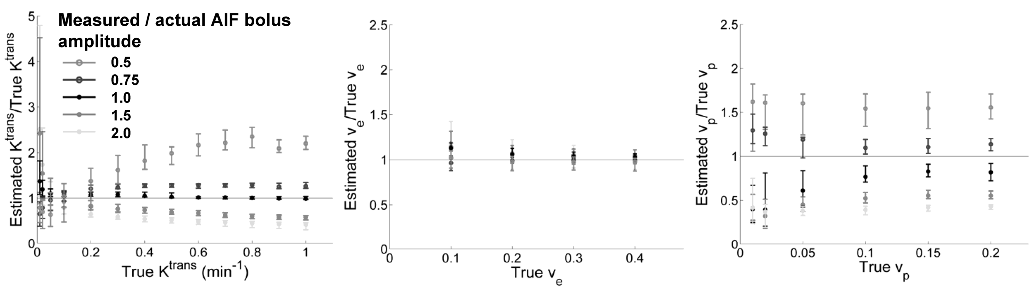

Fig.2. The influence of error in the measured AIF bolus amplitude on parameter estimates K^{trans}, v_e, and v_p. Temporal resolution is 1 s. Data is plotted as median values (dots) and interquartile range (error bars).

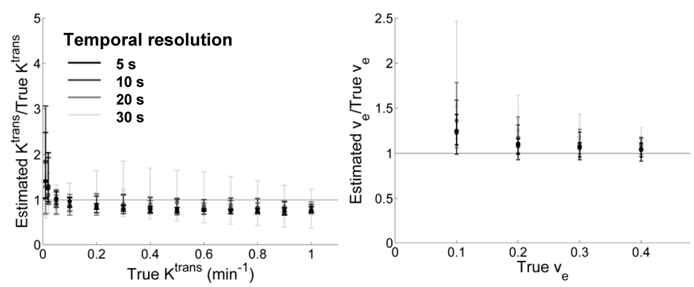

Fig.3. The influence of low temporal resolution on parameter estimates K^{trans} and v_e. Model fitting employed an AIF fitted to a biexponential function. Data is plotted as median values (dots) and interquartile range (error bars). Parameter v_p (not shown) is greatly underestimated.

CONCLUSIONS

A high temporal resolution AIF with a bolus amplitude measurement error is shown to introduce significant inaccuracies in K^{trans} and v_p. The key conclusion is that unless the initial bolus peak amplitude is measured accurately (<25% error), more robust parameter estimates are achieved using a biexponential AIF approach. The biexponential description can accurately estimate small K^{trans} (<0.1 min^{-1}) provided blood volume is low (v_p<0.05) and yields consistent underestimates (~20%) of larger K^{trans} values. This error remains relatively insensitive to temporal resolutions up to 20 s. The only drawback is that blood volumes tend to be significantly underestimated.

REFERENCES: [1] Parker GJ, Padhani AR. In: Tofts PS, ed. Quantitative MRI of the brain. 2003, p.341-364. [2] Henderson E, et al. MRI 1998; 16:1057. [3] Evelhoch JL. JMRI 1999; 10:254. [4] Peeters F, et al. MRM 2004; 51:710. [5] Cheng HL. JMRI 2007; 25:1073. [6] Parker GJ, et al. MRM 2006; 56:993. [7] St Lawrence KS, et al. J Cereb Blood Flow Metab 1998; 18:1365.