Dynamic contrast-enhanced perfusion MRI in the femoral head: comparison of two perfusion models

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Introduction

Dynamic contrast-enhanced T1-weighted imaging is often used to assess the perfusion status of tissues. To this end, several multi-compartment models have been proposed to explain the signal time course (1). The purpose of this Monte Carlo simulation study is to find a model suitable in the femoral head for possible diagnosis of avascular necrosis, at the same time to investigate the estimation accuracy as a function of the frame rate, signal-to-noise ratio (SNR), and total examination time.

Materials and Methods

A model signal-time curve was first established analytically from the time courses obtained from 21 subjects undergoing dynamic contrast-enhanced MR imaging on a 1.5T system. The curve was subsequently sampled at frame intervals of 5, 10, 15, 20, 25, and 30 seconds, with inter-frame noise added at various SNRs varied from 10 to 50. The total examination time governing the wash-out portion included in data fitting was also varied from 5 to 25 minutes. Two multi-compartment models were tested for data analysis. The Brix model (2-3) characterizes the signal time course as a dual exponential shape given by

$$\frac{St - S_0}{S_0} = \frac{A}{(K_{21} - K_{el})}\left[\exp(-K_{el}t) - \exp(-K_{21}t)\right]$$

where A stands for the amplitude of signal change, and K_{21} and K_{el} represent the rates of wash-in and wash-out, respectively. The Tofts model (3-4), on the other hand, describes the signal time course with an inclusion of lesion leakage space effects, in addition to the consideration of extracellular space and kidney excretion. Estimations of perfusion parameters were accomplished by nonlinear least square error curve fitting, with results compared with the model parameters. The absolute percentage estimation errors were obtained with 1,000 repetitions of random noise additions.

Results

Figures 1 to 2 plot the effects of frame rate, SNR, and total exam time on the percentage errors of estimation for the two models. As expected, errors become larger with lower frame, lower SNR, and reduced total exam time, with the only exception that the Tofts model seems to be relatively insensitive to the total exam time. In general, the Brix model shows higher estimation errors than the Tofts model. When the Tofts model is used, errors less than 3% in all perfusion parameter estimations are achievable for SNR of 30 with 10 minute total exam time (Fig.3).

Conclusion

The Tofts model is superior to the Brix model when used in quantitative contrast-enhanced MRI for the femoral head. When an SNR of 30 can be achieved for a total exam time of 10 minutes, less than 3% of errors are expected for the Tofts model.

References

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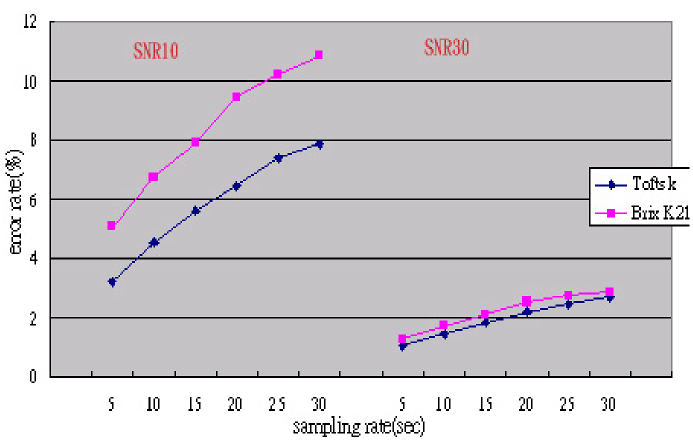

Figure 1. Percentage estimation errors as a function of frame intervals at SNR of 10 (left) and 30 (right). Only the single parameter with the largest errors is shown for each model (K_{21} for Brix model and k for Tofts model). The Tofts model yields higher accuracy than the Brix model on the model signal-time curve obtained from the human femoral head. Similar trends can be seen for the other parameters (results not shown).

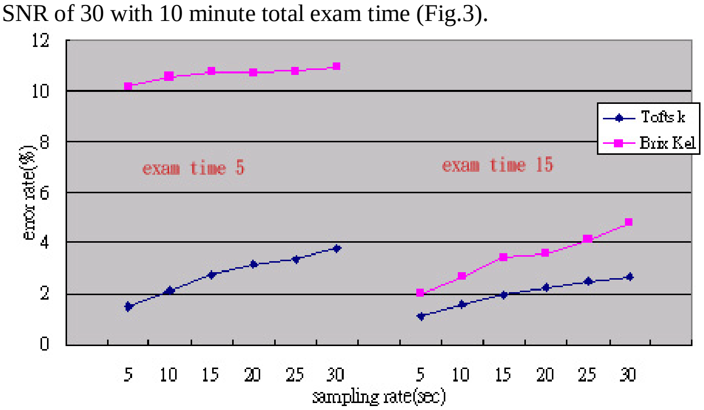

Figure 2. Estimation errors at different lengths of exam time (SNR 30). The Tofts model is relatively insensitive to the total exam time.

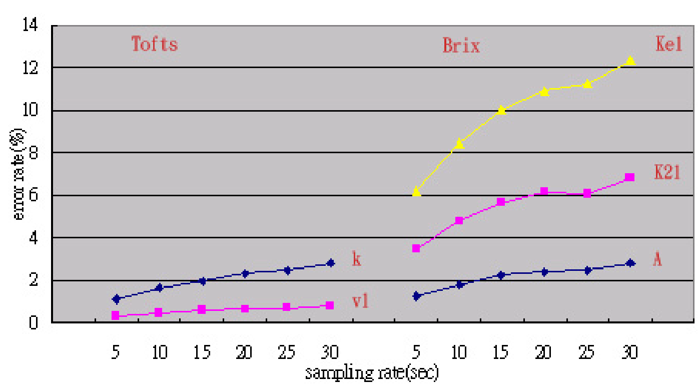

Figure 3. Estimation errors for all parameters in the two models at SNR of 30 and total exam time of 10 minutes. The Tofts model (left) results in less than 3% of errors.