Objective quality criteria for fitting dynamic enhancement curve in perfusion-permeability MRI

D. Balvay[1,2], C. A. cuenod[1,3], F. Frouin[1], G. Calmon[2], S. Nathalie[1,3], O. Clement[1,3]
[1]U494, INSERM, Paris, France, [2]GE Medical Systems, Buc, France, [3]Radiology, HEGP, Paris, France

Introduction

Measurement of tissue perfusion and capillary permeability with MRI is based on the fitting of tissue enhancement curves following a bolus injection of contrast agent. The fitting aims to minimizing the quadratic error. The traditional criteria for the quality of fit (quadratic error Q and correlation coefficient R2), however, are poor indicators and are very sensitive to the noise embedded in the data.
We propose two new criteria base on the residual autocorrelation.

Theory and New Criteria

Quadratic error (Q) and correlation coefficient (R^2) measure not only the adjustment error, but also the amount of noise in the data. When the signal to noise ratio lowers, Q increases and R^2 tends to zero.
Using the fact that the signal of the tissue is temporally highly correlated after contrast injection, whereas the noise is random, we can separate the influence of the noise from the temporal signal.
We calculate the autocorrelation function of the residue of the fit (difference between the data and the model) $R_{rr}(t_k) = 1/ (M-k).\Sigma_i\, r(t_i).r(ti + tk)$, where M is the number of samples. Since the residual is composed of a regular signal x and a decorrelated noise b following a small time interval t_d , than the estimate of $R_{rr}(t_k)$ is equal to the one of $R_{xx}(t_k)$ for $t_k > t_d$. $R_{rr}(t_k) \cong R_{xx}(t_k)$ can be considered as a regularity index of the residual. If the fit is of good quality, the residual should be cleared of regularities ($R_{xx}(t_k) \cong 0$).
The auto-correlation of a regular signal is regular. Using a polynomial regression of $R_{rr}(t_k)$ for $t > t_k$, one can extrapolate the obtained function to zero. $R^*_{xx}(0)$ is an estimate of $R_{xx}(0) = 1/M .\Sigma_i\, x(t_i).x(t_i) = 1 / M . \|x\|^2$, which gives access to the amplitude of the fit error.
We define the residual information fraction $B^* = R^*_{xx}(0) / Q$ and a modified R^2 called $R'^{2*} = 1 - R^*_{xx}(0) / R^*_{dd}(0)$.

Material and methods

Animal model: Nude mice bearing subcutaneous implanted PC3 tumors.
MRI acquisition : Acquisition of 512 T1 weighted FSPGR images (1.13 s/image) following a bolus injection of a macromolecular gadolinium chelate (P792, Vistarem°, Guerbet, France).
Data simulation : Theoretical enhancement curves have been generated with a bi-compartmental model and a real arterial input function. Various levels of noise have been added to these curves prior to apply different fit using adapted and unadapted models.
Criteria test on MR data : Good quality of fitting with adapted model and bad quality of fitting with not adapted model, confirmed with visual analysis, were evaluated by classical (Q and R^2) and new (R'^{2*} and B*) criteria.

Results

The upper part of figure 1 shows the shape of the residual when the fitting model is not well adapted to the data. A continuous component is clearly visible. The lower part of the figure confirms that the autocorrelation function of this residual is far from being an ideal Dirac.

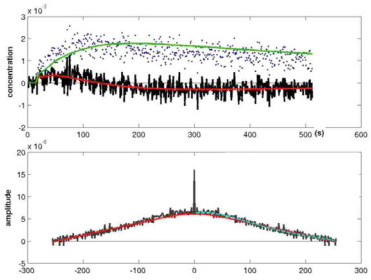

fig. 1

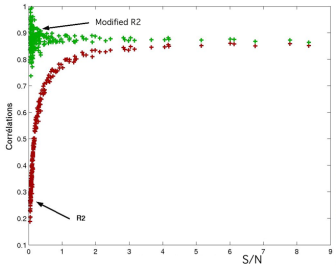

fig 2

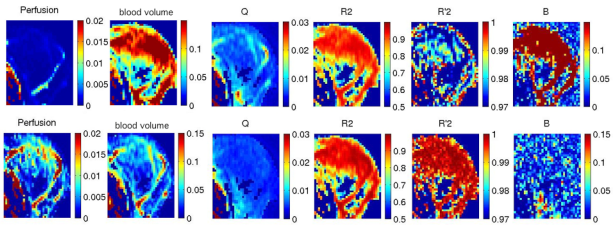

fig 3

Figure 2 demonstrates that the modified R'2 is very stable for very low S/N with the data, whereas the classical R2 falls rapidly to zero.
When the microvascular parameters are calculated on a pixel by pixel basis, generating maps of functional parameters (left part of figure 3), it is possible to construct quality maps in the same time (right part of fig 3). On such maps, the classical criteria (Q and R2) are unable to detect a poor fitting when an unadapted model is used (upper part of the fig 3), whereas the new criteria (R'2 and b) clearly show the errors. The parametric maps of perfusion and blood volume appear very different when using an adapted model (lower part of fig 3), and the quality of the fitting is benchmarked by the new criteria.

Conclusion

The new criteria of quality of fit, based on the analysis of the residual autocorrelation, behave very well even with noisy data. They can be used to test the quality of the fit as well as the pertinence of the mathematical model. The generation of quality maps assures more reliable maps when performing perfusion-permeability MRI.