Investigation of Diffusion Kurtosis Imaging of the organ with plenty of perfusion/flow effect

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Introduction:

Diffusion weighted imaging (DWI) and Apparent Diffusion Coefficient (ADC) have shown potential for assessment of several diseases. The calculation of ADC from DWI data is based on the Gaussian distribution model. However, in biological tissue, we know that the water diffusion is altered by cell membrane and tissue compartment, and the probability distribution function of the water molecules is no longer precisely Gaussian. Kurtosis is a statistical dimensionless metric showing the deviation from the Gaussian shape of the probability distribution. Diffusion Kurtosis Imaging (DKI) was proposed by Jensen et al. [1] to study the deviation of water diffusion from Gaussian distribution, and has been successfully applied to study for more precise neural tissue characterization and better detection of brain diseases. In the organ with plenty of perfusion/flow such as the liver, however, DKI curve fitting is ruined by perfusion/flow component [2]. The goals of this study are (A) to define the DKI model with perfusion/flow component and validate it, and (B) to simulate several patterns of DKI signal decay curves using DKI model with perfusion/flow component defined at (A), and investigate how the conventional DKI fitting is affected by perfusion/flow.

Methods:

(A) Respiratory triggered single-shot echo-planar imaging (EPI) DWI scan with ten b-values (0, 50, 100, 200, 500, 800, 1000, 1250, 1500, 2000 s/mm^2) was performed on a healthy volunteer using 3.0T Achieva R3.2 (Philips Healthcare, Best, the Netherlands). Twenty ROIs were drawn on the liver, and fitted to the following two diffusion kurtosis models;

Conventional DKI fitting model: (*Eq.1*) $S_b = S_0 \exp(-bD + b^2D^2K/6)$

DKI fitting model including perfusion/flow component: (*Eq.2*) $S_b = S_0 \{f \exp(-bD^*) + (1-f) \exp(-bD + b^2D^2K/6)\}$

(B) Using eq.2, diffusion signal decay curves were simulated with these two conditions as follow;

(*Condition I*) fixed D = 0.8 (μm^2/ms), D* = 20 (μm^2/ms), K = 1.0, varied perfusion/flow fraction from 0.05 to 0.4 by 0.05,

(*Condition II*) fixed D = 0.8 (μm^2/ms), D* = 20 (μm^2/ms) and varied K from 0.2 to 1.8 by 0.2 for each perfusion/flow fraction of 0.1, 0.3 and 0.5.

These diffusion signal decay curves were fitted using conventional DKI fitting model (*Eq.1*) to estimate D, K and R^2 was also calculated.

Results and Discussion:

(A) Twenty ROIs gave the diffusion signal decay curve with the perfusion/flow fraction from 0.09 to 0.47. Fig.1a compares R^2 of two fittings using (*Eq. 1*) and (*Eq.2*) when perfusion/flow fraction was larger than 0.2, and Fig.1b is the same comparison of when fraction was smaller than 0.2. It is showing that when perfusion/flow fraction is larger, R^2 is improved by using DKI model including flow component (*Eq.2*) compared to the conventional DKI model (*Eq.1*), and simulating DKI signal decay curve using (*Eq.2*) is feasible.

(B) Table 1 shows estimated D and R^2 of the conventional DKI fitting (*Eq.1*) of the simulated diffusion signal decay curves with (*Condition I*). It indicates that larger perfusion/flow fraction induced overestimation of D and lower R^2. Fig. 2 is the diagram showing the correlation between the simulated K and corresponding estimated K using the conventional DKI fitting (Eq.1) of the simulated diffusion signal decay curves with (*Condition II*). It shows large deviation of estimated K from simulated K due to the perfusion/flow. This might be because DKI model is based on a parabola, and overestimated D makes the vertex of the parabola steeper (Fig.3), and to compensate the deviation of fitting curve from actual diffusion signal decay curve, K value is estimated wrongly.

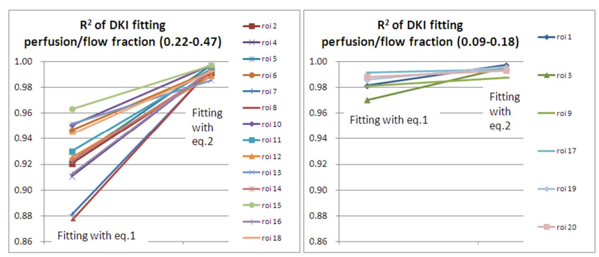

Fig.1: Comparison of R^2 of two fittings using (*Eq.1*) and (*Eq.2*) with large flow fraction (Fig.1a: left), and small fraction (Fig.1b: right)

fraction	0.05	0.1	0.15	0.2	0.25	0.3	0.35	0.4
Estimated D	0.84	0.88	0.93	0.99	1.05	1.12	1.21	1.31
R^2	0.999	0.995	0.989	0.981	0.969	0.954	0.937	0.917

Table 1: Estimated D and R^2 of the conventional DKI fitting (eq.1) of the simulated diffusion signal decay curves with (*Condition I*).

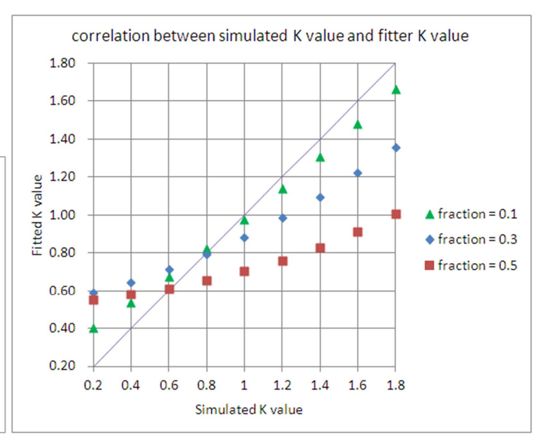

Fig.2: Correlation between simulated K and estimated K using (*Eq.1*).

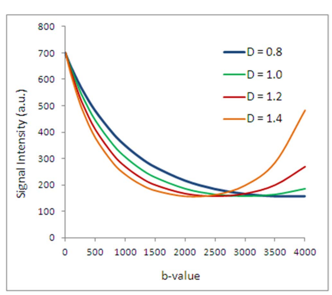

Fig.3: Effect of overestimated D on DKI model (Fixed K = 1.0)

Conclusion:

Our study has shown that the conventional DKI fitting could be affected by large fraction of perfusion/flow, causing lower R^2, overestimated D and large error of estimated K. DKI study for the organ with plenty of perfusion/flow should be done with special care, such as removing data acquired with low b-value or using model including flow component.

References: [1] Jensen et al., Magn. Reson. in Med. 53: 1432-1440 (2005); [2] Suzuki et al., *Proceedings of the 20th Annual Meeting of ISMRM*, 4119 (2012)