Statistical evaluation of different mathematical models for diffusion weighted imaging of normal prostate: repeatability study

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INTRODUCTION

Diffusion weighted imaging is a useful tool in detection and management of prostate cancer, which is the most common cancer among men in developed countries and the second leading cause of cancer-related death in men. The apparent diffusion coefficient (ADC) improves the accuracy of prostate cancer detection and also correlates with the Gleason score. However, the signal decay curve obtained using stronger motion probing gradients (b-values up to 3000 s/mm^2) is better described by a bi-exponential fit in the healthy prostate [1] and prostate cancer [2]. Currently, the optimal mathematical model which provides reasonable repeatability is unknown. We aimed to evaluate different mathematical models for DWI of normal prostate in term of fitting quality and repeatability.

METHODS

Seven healthy volunteers (mean age 55 ± 7) underwent in total four repeated 3T single-shot spin-echo epi based DWI examinations performed on two separate days using surface coils with the following parameters: TR/TE 7000 ms/87 ms, FOV 260×260 mm, matrix 128x128, slice thickness 5 mm, 1628HZ/pixel with 6/8 k-space partial-Fourier acquisition, GRAPPA factor of 2, two different sets of 16 b-values: 1. Clustered distribution- 0, 50, 100, 150, 200, 250, 300, 950, 1000, 1050, 1100, 1150, 1850, 1900, 1950, 2000 s/mm2; 2. Equal distribution- 0, 50, 100, 200, 350, 500, 650, 800, 950, 1100, 1250, 1400, 1550, 1700, 1850, 2000 s/mm^2. The total acquisition time for each set of b-values was 11 minutes and 6 seconds. Eight same sized ROIs (squares of 6x6mm, 3x3 pixels) were placed in the peripheral zone (PZ) and 4 ROIs in the central zone (CZ). Mean signal intensity of each ROI was fitted using following models:

1. Mono-exponential

$$S(b) = S_0 e^{-bADC_{mono}}$$

2. Streched exponential

$$S(b) = S_0 e^{-(bADC_{streched})^{\alpha}}$$

3. Kurtosis

$$S(b) = S_0 e^{(-bADC_{kurtosis} + \frac{1}{6} b^2 ADC_{kurtosis}^2 K)}$$

4.Bi-exponential

$$S(b) = S_0((1-f)e^{-bD_s} + fe^{-bD_f})$$

The fitting procedure was performed using the lsqnonlin MATLAB algorithm (Mathworks Inc., Natick, MA, USA). Multiple initialization values were set to limit possible effect of local minima in the fitting:

A Gaussian smoothing filter with a kernel size of 3x3 was applied as a pre-processing step to improve the signal to noise ratio.

To determine the best regression, corrected Akaike information criterion (AIC$_c$): and F-test with 5% level of significance were used.

$$AIC_c = N \ln\left(\frac{SS}{N}\right) + \frac{2(K+1)(K+2)}{N-K-2}$$

where N is the sample size, K is the number of parameters, SS the sum of squares of the vertical distance of the points from the curve.

$$F = \frac{(SS_{null} - SS_{alt}) / SS_{alt}}{(DF_{null} - DF_{alt}) / DF_{alt}}$$

where SS the sum of squares of the vertical distance of the points from the curve, K the number of parameters, DF=N-K are the degrees of freedom.

Reliability and repeatability of each parameter of each model was assessed using Shrout-Fleiss analysis, ICC(3,1) [3].

RESULTS

In total 336 ROIs were evaluated. Kurtosis model provided the best regression for PZ as well as CZ (table 1). Parameters of bi-exponential model had the lowest reliability and repeatability (ICC values for all parameters were below 0.50 with exception of *f* parameter of PZ acquired with clustered b-value distribution) while the mono-exponential model demonstrated the best reliability and repeatability (ICC values for *ADC* parameter were above 0.83). The parameters of kurtosis model had ICC values above 0.71 and were similar to the ICC values of the stretched model parameters.

The parameters of bi-exponential and kurtosis model based on clustered b-value distribution had higher reliability and repeatability compared with the similar parameters calculated using equal b-value distribution.

Table 1: Fraction of ROIs in CZ and PZ for clustered and equally distributed b-values. Higher percentage represents large proportion of ROIs described better by the first model of individual comparison.

		Clustered distribution		Equal distribution	
		PZ	CZ	PZ	CZ
AIC	stretched vs mono	98%	100%	98.8%	100%
	kurtosis vs mono	99.2%	100%	100%	100%
	biex vs mono	99.2%	100%	100%	100%
	kurtosis vs streched	98.8%	88.1%	96.4%	81%
	biex vs streched	98.8%	97.6%	96%	88.1
	biex vs kurtosis	45.6%	63.1%	48%	48.8%
F-ratio	stretched vs mono	97.6%	100%	98.4%	100%
	kurtosis vs mono	99.2%	100%	99.6%	100%
	biex vs mono	99.2%	100%	100%	100%
	biex vs streched	98%	95.2%	96%	86.9%
	biex vs kurtosis	35.3%	48.8%	36.1%	36.9%

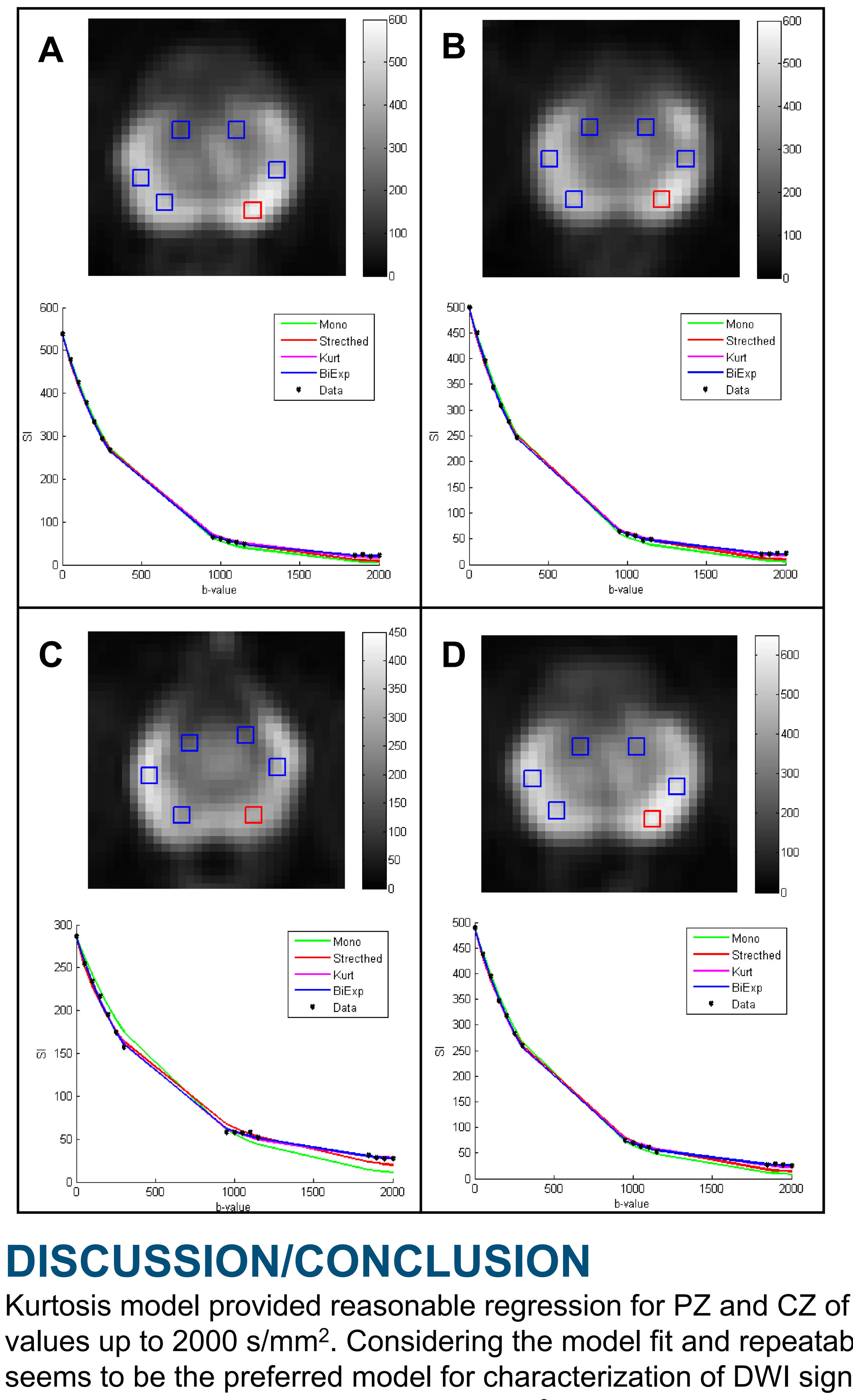

Figure 1 Representative example of 4 repeated scans of one healthy volunteer with placement of ROIs. The DWI signal decay curve of mean signal intensity (SI) of ROI in red color is shown. Bi-exponential model has the smallest sum of squares of the vertical distance of the points from the curve

DISCUSSION/CONCLUSION

Kurtosis model provided reasonable regression for PZ and CZ of normal prostate using b-values up to 2000 s/mm^2. Considering the model fit and repeatability, kurtosis model seems to be the preferred model for characterization of DWI signal decay of normal prostate using b-values up to 2000 s/mm^2.

REFERENCES

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