Optimization of b-value distribution for biexponential DWI of normal prostate

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Purpose

Diffusion weighted imaging (DWI) has been shown to be particularly valuable in prostate cancer detection and characterization. The apparent diffusion coefficient (*ADC*), which is calculated from DWI data using a mono-exponential fit, improves the accuracy of prostate cancer detection. However, the signal decay curve obtained using higher b-values (up to 3000 s/mm^2) is better described by a biexponential fit in the healthy prostate (1) and prostate cancer (2). In this study we aimed to determine the optimal b-value distributions for biexponential DWI of normal prostate using both Monte-Carlo simulations and in-vivo measurements.

Methods

In all simulations, signal intensity decay curves of normal prostate gland tissue were calculated according to the following biexponential decay function (eq.1).

$$\frac{S(b)}{S(0)} = (1-f)\cdot\exp(-b\cdot Ds) + f\cdot\exp(-b\cdot Df)$$

where f is the fraction of fast diffusion, Ds represents the slow components of diffusion and Df represents the fast components of diffusion.

Four different levels of Rician noise were added to the simulated signal which was based on literature values (1, 2). The total error (E_{tot}) (eq. 2). was used as the optimization criterion.

$$E_{tot} = \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(f_i - f\right)^2}}{f} + \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Df_i - Df\right)^2}}{Df} + \frac{\sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(Ds_i - Ds\right)^2}}{Ds}$$

where f, Df and Ds are the literature values used to generate the signal values while f_i, Df_i, Ds_i are the fitted results of the i-th iteration and E_{tot} is the total error.

An optimal distribution of 13 b-values, in addition to the initial three b-values of 0, 50 and 100 s/mm^2, for biexponential DWI of the normal prostate gland was generated using the following four individual optimization methods:

1. B-values were added consequently to the three initial b-values of 0, 50 and 100 s/mm^2.
2. Starting with 41 evenly distributed initial b-values the number of b-values was consecutively decreased.
3. Using the optimal distribution from 1st method, b-values were moved in an iterative stepwise step.
4. Distributions of 16 b-values were randomly generated. This entire process was repeated 5000 times.

In order to further evaluate our findings, eight healthy volunteers (mean age 52±7 years) underwent in total four 3T single-shot spin-echo epi based DWI examinations performed on two different days within one week with the following parameters: TR/TE 7000 ms/87 ms, FOV 260×260 mm, matrix size 128x128, slice thickness 5 mm. Two different distributions of 16 b-values were used for the calculation of f, Df , Ds:

1. Clustered distribution: 0, 50, 100, 150, 200, 250, 300, 950, 1000, 1050, 1100, 1150, 1850, 1900, 1950, 2000 s/mm^2
2. Equal distribution: 0, 50, 100, 200, 350, 500, 650, 800, 950, 1100, 1250, 1400, 1550, 1700, 1850, 2000 s/mm^2

The selected clustered distribution was the optimal b-value distribution based on the results of the simulations. The first seven b-values of the equal distribution were used for *ADC* calculation. Biexponential parameters, obtained using both b-value distributions, and *ADC* were compared in terms of the reliability and repeatability using of intra-class correlation coefficients based on Shrout-Fleiss analysis.

Results

All four optimization methods produced similar optimal b-value distributions. Using low noise levels, the optimal b-value distribution formed three separate clusters at low (0-400 s/mm^2), mid-range (650-1200 s/mm^2) and high b-values (1700-2000 s/mm^2). Higher noise levels resulted into fewer b-values in the high-range of the optimal b-value distribution. The clustered b-value distribution demonstrated better measurement reliability and repeatability in Shrout-Fleiss analysis compared to 16 equally distributed b-values (Figure 1).

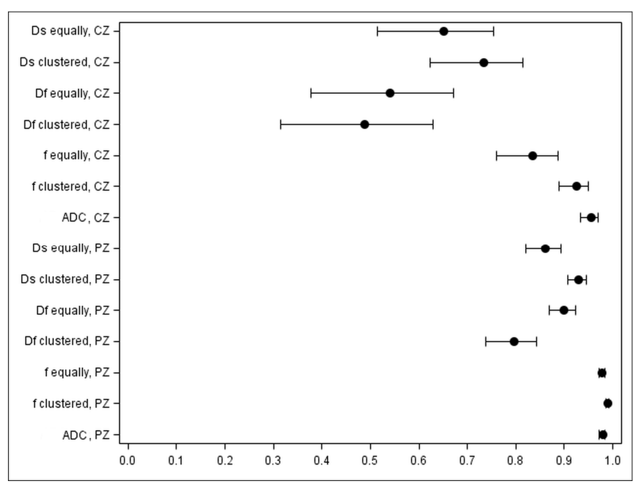

Fig. 1 Intra-class correlation coefficients

Conclusions

The optimal b-value distribution for biexponential DWI of normal prostate using high b-values was found to be a clustered distribution with b-values concentrated in the low, mid and high ranges and was shown to improve the estimation quality of biexponential DWI parameters based on in-vivo experiments.

References

1. Mulkern et al. Magn Reson Imaging 2006; 24:563-568.; 2. Shinmoto et. al. Magn Reson Imaging 2009; 27:355-359.