Multi-echo T2 modelling to predict PIRADS 2.0 score

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Synopsis

To investigate if Luminal Water Imaging (LWI), which models multi-compartment T2 decay, can predict the PIRADS 2.0 score of a region of interest (ROI). 52 patients were scanned using both standard mp-MRI and a 32-echo T2 sequence, ROIs were placed in areas of suspected lesion and suspected benign tissue and then these ROIs were each given a PIRADS 2.0 score. The results show that LWI can predict PIRADS 2.0 score as well as the Apparent Diffusion Coefficient (ADC).

Introduction

Luminal Water Imaging (LWI) is a method for calculating the percentage volume of lumen within a voxel using a multi-echo T2 sequence. LWI is strongly related to the fractional amount of luminal space in prostatic tissue[1] and a recent study showed LWI to be feasible for the detection and grading of Prostate Cancer (PCa)[2]. Multi-echo T2 sequences do not suffer from the distortion and signal pile-up often observed in EPI-based diffusion imaging. The PIRADS 2.0 method of PCa detection and grading uses multi-parametric MRI. Not only does this method use diffusion images, which are prone to distortion due to magnetic susceptibility differences, but PIRADS also classifies a significant proportion of lesions as indeterminate[3-5]. The aim of this work was to examine the ability of LWI alone to predict PIRADS scores.

Methods

Model The LWI model proposed in this work imposes constraints on the original proposed by Sabouri et al[1]. The model relating the Signal S to the distribution p of T2 values is:

$$S = M_0 \int_0^\infty p(T2)exp(-\frac{TE}{T2})dT2$$

where M_0 is the overall magnitude of the signal and TE is the echo time. LWI previously used a smoothed non-negative least squares (NNLS) fitting over a large number of variables to produce the distribution p[6]. Most voxels have previously shown signal components from two main tissue compartments[1,2] so constraining the voxels to have no more than two compartments could provide a more robust fitting. Due to their ubiquity and simplicity, in this work p is constrained to be composed of two Gaussian distributions. Six parameters were estimated voxel-wise: overall scaling (M_0), relative fraction between the two compartments (α), mean and standard deviation of the short T2 peak (μ_1 and σ_1) and mean and standard deviation of the long T2 peak (μ_2 and σ_2). The Luminal Water Fraction (LWF) was calculated as the area under the long T2 component divided by the area under both components.

Data 52 patients were imaged using axial T2, diffusion and multi-echo T2 sequences. The scan parameters are included in Table 1. A board-certified radiologist contoured 51 lesions in 52 patients on all modalities, which were confirmed as cancers following targeted biopsy. Regions of interest (ROIs) were also placed in 34 areas of normal tissue in each of the subjects, all of which were histologically confirmed as benign. Then using the traditional multi-parametric MRI (mp-MRI) images a PIRADS score was attributed to each ROI. This PIRADS score is between 1-5 where 1-2 is unlikely clinically significant, 3 is indeterminate and 4-5 is likely clinically significant.

Comparisons The ability of LWI to differentiate between PIRADS scores was compared to that of the Apparent Diffusion Coefficient (ADC) using a linear mixed effects model and its ability to predict PIRADS score was assessed using a Receiver Operating Characteristic (ROC) analysis. Sensitivity and specificity values were calculated for the optimal threshold but the threshold value can be changed to trade off sensitivity for specificity and vice versa. Three comparisons were made:

- PIRADS 1&2 v PIRADS 3 – assesses how well LWF can tell a score of unlikely clinical significance from an indeterminate score
- PIRADS 3 v PIRADS 4&5 – assesses how well LWF can tell an indeterminate score from a clinically significant score
- PIRADS 1&2 v PIRADS 3,4&5 – assess how well LWF can tell a score that does not require further action from one that does

Results

Figure 1 shows scan parameters for the 32-echo acquisition. Figure 2 shows the results of the statistical tests. The p-values show that there is a significant difference between all of the categories compared. The Area Under the Curve (AUC) values show that the LWF predicts PIRADS score as well as ADC. Figure 3 shows an example LWF map of the prostate. Highlighted in red is a PZ 3+4 tumour.

Discussion

Despite the bias of this experiment towards ADC, given that the PIRADS scoring is based upon ADC images, the AUC results show that LWF is as good as and in some cases better than ADC at predicting PIRADS scores. Using these particular classifiers, the LWF offers more specificity than ADC for the 3v4,5 and 1,2v3,4,5 tests but sacrifices some sensitivity as a result. However, the sensitivity and specificity values were calculated for the optimal threshold and the AUC suggests that the threshold value could be changed to trade off less specificity for more sensitivity.

Conclusion

The ability of LWI to predict PIRADS score combined with the fact that T2 imaging suffers far less from artefacts means that LWI is a promising new technique for detecting and grading PCa.

Acknowledgements

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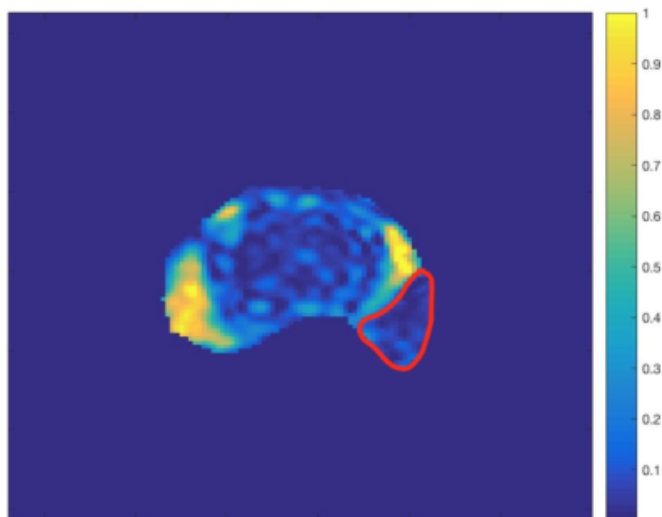
Figures

Parameter	32-echo
Number of echoes	32
TE (ms)	31.25
TR (ms)	8956
Acquisition voxel size (mm³)	2x2x4
FOV (mm³)	180x180x26
Scan Duration (mm:ss)	05:49

The scan parameters of the proposed 32-echo acquisition.

Scores	1,2v3				3v4,5				1,2v3,4,5			
Test	p-val.	AUC	Sens.	Spec.	p-val.	AUC	Sens.	Spec.	p-val.	AUC	Sens.	Spec.
LWF	0.0098	0.684	74.5	62.5	0.0050	0.771	75.0	72.2	0.0000	0.779	72.6	79.4
ADC	0.0008	0.681	68.6	66.7	0.0498	0.739	80.0	66.7	0.0000	0.764	84.3	63.6

The results of the statistical tests. There is a significant difference between all categories and the ROC analysis shows that the LWF predicts PIRADS score as well as ADC. Sensitivity and specificity values were calculated for the optimal threshold but the threshold value can be changed to trade off sensitivity for specificity and vice versa.

LWF map of the prostate. Note the higher LWF in the peripheral zone (PZ), consistent with histological findings of large regular acini and loosely woven stroma in the PZ. Highlighted in red is a PZ 3+4 tumour.