

## Contrast-to-noise ratio in extrapolated and measured high b-value diffusion weighted prostate MR images

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### Introduction:

Increasing the b-value in diffusion weighted MRI (DWI) above  $\sim 1000$  s/mm<sup>2</sup> has the potential to improve the detection of prostate cancer. A recent study showed improved diagnostic performance when evaluating diffusion weighted images with  $b=2000$  s/mm<sup>2</sup> compared to  $b=1000$  s/mm<sup>2</sup> at 1.5T [1]. Conversely, other studies have found no increased performance evaluating ADC maps calculated using  $b=2000$  s/mm<sup>2</sup> versus  $b=1000$  s/mm<sup>2</sup> at 3T [2, 3]. This may be attributed to the lower SNR associated with stronger diffusion weighting and the need for longer TE at higher b-values, leading to a further reduction of SNR and increased artifacts. Instead of by measurement, high b-value DWI images can also be obtained by extrapolation, by using ADC fits to a set of DWI images acquired at lower b-values. Such extrapolated images are available in the post-processing packages of some vendors, aiming to combine the diagnostic performance of high b-value images with the improved SNR and reduced artifacts of DWI at lower b-values. In this work we compared extrapolated  $b=1400$  s/mm<sup>2</sup> MR images with measured ones, evaluating image intensities and contrast-to-noise ratios (CNRs) between prostate cancer suspicious lesions and normal-appearing tissue.

### Methods:

Eleven patients with biopsy proven prostate cancer were included in this study. Written informed consent was obtained from each. All imaging was performed on a 3T MRI system (Trio with TIM, Siemens, Erlangen) with external spine and body phased array coils. No endorectal coils were used. Each patient received high-resolution T2-weighted imaging in three orthogonal planes, as well as two DWI scans: one with a low range of b-values (DWI<sub>L</sub>), and one with a higher range of b-values (DWI<sub>H</sub>). Acquisition parameters for DWI<sub>L</sub> were TR/TE = 3100/59 ms; b-values 0, 100, 400, and 800 s/mm<sup>2</sup>; equal scan time per b-value 64 s. Acquisition parameters for DWI<sub>H</sub> were TR/TE = 3400/68 ms; b-values 100, 500, and 1400 s/mm<sup>2</sup>; scan times per b-value 43, 76 and 140 s, respectively. DWI<sub>L</sub> was fitted with a mono-exponential model to yield ADC maps in two ways, one including perfusion effects (i.e. including  $b=0$  s/mm<sup>2</sup>, ADC<sub>LP</sub>), and one including diffusion effects only (i.e. excluding  $b=0$  s/mm<sup>2</sup>, ADC<sub>LD</sub>). These fits were then used to calculate extrapolated DWI images at  $b=1400$  s/mm<sup>2</sup> (eDWI<sub>P</sub> and eDWI<sub>D</sub>, respectively). ADC maps were also calculated for DWI<sub>H</sub> (ADC<sub>H</sub>) using all b-values. ROIs were drawn on ADC maps in areas suspicious of prostate cancer based on T2-weighted as well as diffusion weighted imaging [18 total; 14 peripheral zone (PZ); 4 central gland (CG)]. ROIs with normal-appearing tissue in PZ and, where applicable, CG were also drawn in each patient. The ROIs were transferred to all other images, and corrected for organ motion between scans where necessary. Care was taken to place the ROIs in areas of relatively homogeneous image intensity in order to minimize the influence of physiological variations on CNR measurements.

The CNR was defined as  $CNR = (I_s - I_n) / \sqrt{V_s \cdot SD_s^2 + V_n \cdot SD_n^2}$ , where  $I_s$ ,  $I_n$ ,  $SD_s$  and  $SD_n$  are the mean image intensity and standard deviation in suspicious and normal-appearing ROIs within the same patient and prostatic zone, respectively, and  $V_s$  and  $V_n$  are their volumes. In effect, this definition of CNR represents the mean contrast between two ROIs divided by the uncertainty of this contrast. Weighting by ROI volume is necessary to compensate for the dependency of relative uncertainties on ROI size. CNRs were calculated for all images and adjusted for acquisition time differences assuming a square-root relationship between signal-to-noise ratio (SNR) and scan time.

Image intensities and CNRs were compared using the Wilcoxon signed-ranks test for paired data, and a  $p$ -value  $<0.05$  was considered statistically significant. Multiple comparisons were accounted for by reducing the significance level according to the Bonferroni method.

### Results and Discussion:

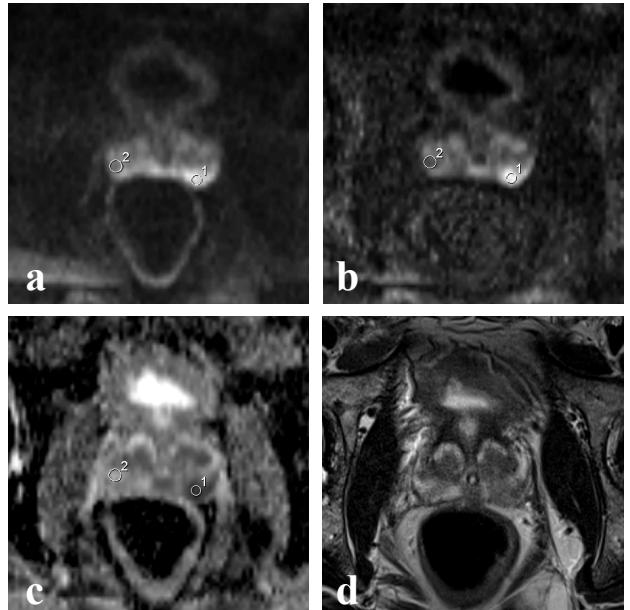
Figure 1 shows an example of measured (a) and extrapolated (b)  $b=1400$  s/mm<sup>2</sup> (eDWI<sub>D</sub>) prostate images. The ADC<sub>LD</sub>-map used to calculate the extrapolated image and a T2-weighted image at the same level of the prostate are also shown (c and d). Example ROIs are indicated in the diffusion images in an area suspicious for prostate cancer (1) and a normal-appearing area (2). As expected when excluding perfusion effects, ADC<sub>LD</sub> was significantly lower than ADC<sub>LP</sub> in suspicious lesions (mean difference  $40.7 \cdot 10^{-6}$  mm<sup>2</sup>/s,  $p < 0.0005$ ). In turn, ADC<sub>H</sub> was significantly lower than ADC<sub>LD</sub> (mean difference  $213.9 \cdot 10^{-6}$  mm<sup>2</sup>/s,  $p < 0.0005$ ), suggesting that a mono-exponential model may not be sufficient to fully describe the effects of water diffusion on image intensity in prostate, an effect that has been previously described in literature [4]. In agreement with the ADC results, the mean intensity in suspicious lesions was significantly higher in eDWI<sub>D</sub> than in eDWI<sub>P</sub>, and the mean intensity in suspicious lesions in the measured  $b=1400$  s/mm<sup>2</sup> images (mDWI<sub>H</sub>) was significantly higher than in eDWI<sub>D</sub> ( $p < 0.0005$  in both cases). For the CNR however, no significant difference was found between eDWI<sub>D</sub> and mDWI<sub>H</sub> ( $p = 0.571$ ). On average, CNRs were higher in eDWI<sub>D</sub> than in mDWI<sub>H</sub>, but these differences did not reach statistical significance ( $p = 0.06$ ). On the other hand, CNRs were significantly higher in eDWI<sub>D</sub> than in eDWI<sub>P</sub> ( $p < 0.0005$ ). These results suggest that the non-significant difference between eDWI<sub>D</sub> and mDWI<sub>H</sub> may be due to a lack of statistical power, and that extrapolated high b-value images obtained excluding perfusion effects may exhibit slightly improved CNR compared to measured images. Interestingly, CNRs in ADC<sub>LD</sub> were significantly higher than in ADC<sub>LP</sub> ( $p = 0.001$ ) and than in ADC<sub>H</sub> ( $p < 0.0005$ ). No significant difference in CNR was observed between ADC<sub>LP</sub> and ADC<sub>H</sub>, in seeming agreement with the observations in [2] and [3] that using ADC maps based on higher b-values does not yield improved diagnostic performance.

### Conclusions:

The results of this study indicate that the image quality of extrapolated  $b=1400$  s/mm<sup>2</sup> images is comparable to that of measured images in terms of CNR between suspicious lesions and normal-appearing tissue. They suggest that the CNR may even be slightly better in extrapolated than in measured images, provided that they are created using ADC fits which exclude perfusion effects. Whether this has any consequences in terms of diagnostic performance should be investigated by comparison with histopathology.

**References:** [1] K. Katahira et al., *Eur Radiol* Jul, 18 (2010); [2] C.K. Kim et al., *AJR* 194:W33-7 (2010); [3] K. Kitajima et al., *Magn Reson Med Sci* 7:93-9 (2008); [4] R.V. Mulkern et al., *Magn Reson Imaging* 24:563-68 (2006)

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**Figure 1.** Measured (a) and extrapolated (b) DWI images at  $b=1400$  s/mm<sup>2</sup>, ADC map used to calculate the extrapolated image using b-values of 100, 400 and 800 s/mm<sup>2</sup> (c), and T2-weighted image of the same slice (d). Suspicious and normal-appearing regions are indicated by ROIs (1) and (2), respectively.