# Prostate DWI co-registration via maximization of hybrid statistical likelihood and cross-correlation for improved ADC and computed ultra-high b-value DWI calculation

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**Introduction** Diffusion weighted imaging (DWI) has gained significant attention for prostate cancer imaging as it was found to be highly useful for tumor localization[1]. The most common uses of DWI for prostate cancer analysis are for constructing apparent diffusion coefficient (ADC) maps, as well as for obtaining computed high b-value images with b-values greater than 1500 s/mm$^2$. As both the computation of ADC maps and computed high b-value images are derived from a set of DWI acquisitions across multiple b-values, any misalignments between the DWI acquisitions can result in degradation and inaccuracies in the derived images. To better mitigate the issue of misalignment, image registration of DWI acquisitions across multiple b-values is a necessary step. However, to the best of our knowledge, DWI co-registration across multiple b-values has not been well explored. Therefore, we propose a novel method to co-register high and low *b*-value DWI acquisitions together for improved ADC map computation and better visualization and localization of the prostate tumour.

**Method** For registering DWI acquisitions, some important challenges include: i) deformation due to imaging parameters, ii) low SNR in high *b*-value DWI acquisitions, and iii) movement of patients. To overcome these issues, the proposed method adapts b-spline based non-linear registration[2] by introducing a new hybrid similarity metric. The hybrid metric employs the optimized combination of statistical likelihood (SL) and cross correlation (CC) to adaptively accommodate for differences between DWI acquisitions at different *b*-values, where acquisitions with more similar *b*-values can be better handled using SL while the acquisitions with large *b*-value differences can be better handled by CC.

Given that the target DWI acquisition ($f_b$) with b-value ($b$) and the reference DWI acquisition ($f_{ref}$), the optimal transformation ($T$) is computed as:

$$T(b) = \underset{T}{\operatorname{argmax}} \prod_{b\in B}\prod_{s\in S}\left(\alpha(b)P\left(f_b\big(T_b(s)\big)\middle|f_{ref}(s)\right)\right) + \sum_{b\in B}\sum_{s\in S}\beta(b)\frac{\left(f_b\big(Tb(s)\big)-\overline{f_b}\right)\left(f_{ref}(s)-\overline{f_{ref}}\right)}{\sigma_{f_b}\sigma_{f_{ref}}}$$

where $\alpha(b) = \frac{b_{MAX}-b}{b_{MAX}}$, $\beta(b) = \frac{1}{b_{MAX}}b$, and $P\left(f_b\big(T_b(s)\big)\middle|f_{ref}(s)\right)$ is the probability of $f_b\big(T_b(s)\big)$given $f_{ref}(s)$.

For this study, a patient case was acquired using a Philips Achieva 3.0T under the institutional research ethics board approval. The axial single-shot echo-planar DWI sequences were performed with the following imaging parameters: TR ranged from 3336 - 6178 ms with a median of 4890 ms, and TE ranged from 61 - 67 ms with a median of 61 ms. The resolution of the signal acquisitions was 1.56 x 1.56 mm$^2$. Slice thickness ranged from 3.0 - 4.0 mm with a median of 3.5 mm. A total of seven different *b*-values was used with the maximum *b*-value being $b$ = 1000 s/mm$^2$. The proposed registration method, along with SL and CC, was then employed to register the DWI acquisitions and then compared with the unregistered acquisitions.

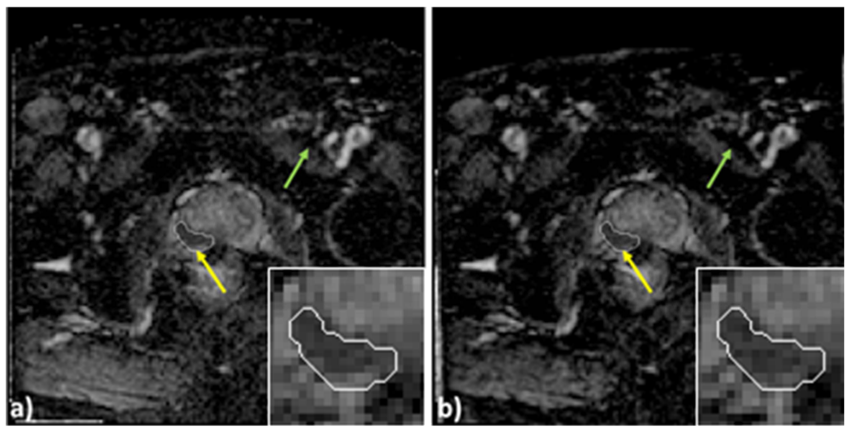


**Fig. 1** ADC computed from a) acquired and b) registered DW images. The upper right arrows (green) represent the ADC artifacts due to misalignment of DW images and bottom arrows (yellow) show the segmented prostate tumour region.

**Results and Discussion** To evaluate the proposed registration, the contrast-to-noise ratio (CNR) were compared between both registered images and the original unregistered images. CNR was calculated at the different b-values based on a manually segmented tumour region and its surrounding regions. As shown in Table 1, CNR from the registered images using the proposed method was higher than that from originally acquired images as well as the registrations based on SL and CC. Moreover, in order to observe the performance of the proposed method on the quality of ADC map derivation, the ADC map was computed for the proposed method, and the unregistered acquisitions, and their CNR were measured. From Table 2, ADC from the registered images obtained using the proposed method had higher CNR, which it can be visually confirmed from Fig. 1 as the contrast between the tumor region and the surrounding regions is improved (see 1b)). Another benefit is that the ADC map contained fewer ADC artifacts caused by DWI misalignment (shown in right upper regions in Fig. 1). In conclusion, the proposed method is capable of producing better alignment between DWI acquisitions at multiple *b*-values so that it aids radiologists and clinicians to diagnose the prostate cancer by providing the improved quality of ADC maps and computed high b-value images.

**Table 1.** CNR for different *b*-values from acquired DW images and registered images (dB)

| ***b*-values** | **Pre-reg** | **Post-reg** | | |
|---|---|---|---|---|
| | | **SD** | **CC** | **Hybrid** |
| 10 | 1.31 | 1.36 | 1.30 | **1.36** |
| 20 | 1.26 | 1.35 | 1.25 | **1.35** |
| 50 | 1.24 | 1.40 | 1.22 | **1.40** |
| 75 | 1.22 | 1.40 | 1.21 | **1.40** |
| 100 | 1.20 | 1.35 | 1.21 | **1.35** |
| 1000 | 1.36 | 0.35 | 1.94 | **1.94** |
| **Total** | **1.26** | 1.20 | 1.36 | **1.45** |

**Table 2.** CNR of ADC from original and registered images

| ***b*-values** | **Pre-reg (dB)** | **Post-reg (dB)** |
|---|---|---|
| ADC | 2.11 | 2.26 |

## Reference

[1] Haider, Masoom A., *et al*. *American Journal of Roentgenology* 189.2 (2007): 323-328.

[2] Rueckert, D., *et al. Medical Imaging, IEEE Transactions on* 18.8 (1999): 712-721.