

## A fast and simple post-processing procedure for the correction of mis-registration between sequentially acquired stations in whole-body diffusion weighted MRI

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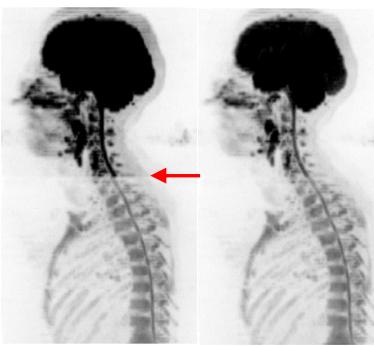
**Introduction:** Whole-body diffusion weighted imaging (WBDWI) is gaining popularity as a method for detecting bony metastases. Signal from suspect malignancies on fat suppressed WBDWI images acquired using high b-values ( $\sim 1000$  s/mm $^2$ ) is hyper-intense compared with background tissues, providing excellent image contrast for disease detection [1, 2]. WBDWI images are generally acquired in sequential stations, each comprising 30-50 axial slices, which are then 'stacked' together for multi-planar and maximum intensity projection displays using visualization software [1]. However, image stack misalignment and differences in signal intensity scaling between sequentially acquired stations (see **Figure 1** and **Figure 2**) can lead to diagnostic difficulties between and within studies. Image stack misalignment can be attributed to variations in the calculated base frequency of water at each imaging station due to differences in shim settings [3]. Partial correction of this effect can be achieved by recording the base frequency of the first station acquired, and then by enforcing the same base frequency for each subsequent station acquisition [3]. Whilst improvements in the spatial alignment between stations can be achieved using this method, results are not uniform and mis-alignments may still be observed, particularly at higher field strengths. Furthermore, the technique does not account for the variations in signal intensity between stations, especially at the transition from the neck into the thorax. Here, we describe a fast, simple and robust post-processing method for correcting these artifacts.

**Methods:** *Station Correction* – The correction procedure proposed relies on the assumption that the image slices on either side of an imaging station boundary should contain similar image information. In principle, this depends on the slice thickness used. For the typical 5mm slice thickness used for WBDWI, this may be assumed (see **Figure 3** for example images acquired on either side of a boundary in the neck). Our algorithm first attempts to normalise the signal intensity between stations using a simplistic model in which the difference in signal intensity between stations is described by a linear scaling term. The scaling term,  $k$ , is determined by minimizing the mean-square-difference (msd) between the cumulative-frequency curves of image intensity on either side of the station boundary;

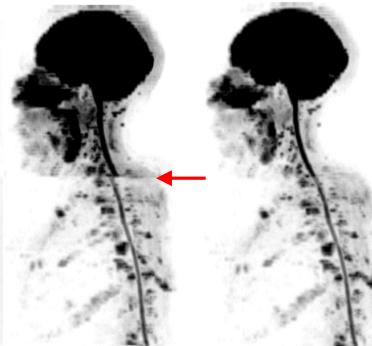
$$k = \arg \min_{k^*} \left[ \{C(k^* I_+) - C(I_-)\}^2 \right]$$

where  $C(\bullet)$  represents the cumulative frequency of image intensity, and  $I_-$  and  $I_+$  represent the images either side of the boundary. Once signal intensity normalization has been achieved, alignment is performed between images  $I_-$  and  $I_+$  in the phase-encode direction to account for the spatial shift. Due to the small search size of registration, this is done by iteratively shifting  $I_+$  one pixel at a time along the phase encode direction and finding the shift that produces the minimum mean-square-difference between images. The determined pixel shift and scaling constant are then applied to the rest of the station to complete the correction. For more than two imaging stations, this is done sequentially, head downwards, comparing each station to its neighbor. For multiple b-value data, the correction is performed using the lowest b-value and the correction values are applied to the higher b-values. This reduces the influence of noise and also ensures the technique does not affect ADC calculation. *Validation of technique* – To demonstrate the applicability of the correction method, examples are provided from both a male volunteer and a patient diagnosed with bony metastases from primary prostate cancer. Images were acquired over two stations; one consisting of 50 axial slices covering from the top of the skull to the top of the thoracic region, and another consisting of 50 axial slices covering the rest of the thorax. The method proposed by Li *et al.* [3] was used to fix the base frequency of water for both stations at acquisition. From previous experiences at 1.5T, the continuity between these two stations has been observed to be especially poor. Images were acquired at 1.5T (Avanto, Siemens Healthcare, Erlangen, Germany) using the following imaging parameters: TE = 62ms, TR = 14000ms, NeX = 4, readout bandwidth = 1960Hz/px, b = 0, 900 s/mm $^2$ , slice thickness = 5mm, pixel resolution = 2.5 x 2.5 mm $^2$ , base resolution = 160 x 160. Images were compared before and after correction with the post-processing scheme described as sagittal maximum-intensity projections (MIP) through the entire reconstructed volume.

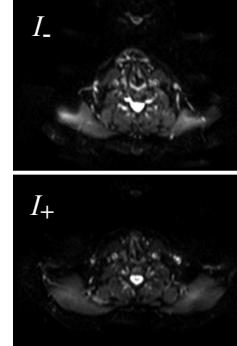
**Figure 1**



**Figure 2**



**Figure 3**



**Figure 1:** Sagittal MIPs of the reconstructed DWI data for the male volunteer before (left) and after (right) correction with the proposed technique. The station boundary is indicated with a red arrow. Post correction image shows significant improvement in the homogeneity between slices. **Figure 2:** Sagittal MIPs of DWI data in a prostate cancer patient before (left) and after (right) correction. Note again the improvement in image quality after correction. **Figure 3:** Images on either side of the station boundary for the male volunteer ( $b = 0$  s/mm $^2$ ). Both images display similar information as assumed by the correction algorithm.

**Results:** **Figure 1** and **Figure 2** are MIPs of a volunteer and a patient respectively before (left) and after (right) correction with the post-processing technique. Mis-alignment and non-uniform signal intensity is observed between the stations, even after normalizing the base frequency as proposed by Li *et al.* [3] (red arrows). Significant improvement was achieved after post-processing with our proposed technique. We have extended this technique to all imaging stations in WBDWI studies conducted at our institution with good results. We are currently evaluating this approach in a prospective trial.

**Discussion and Conclusion:** A simple and robust algorithm for correction of station mismatch in WBDWI data has been described. This method not only improves the spatial alignment between stations after base frequency normalization, but also corrects for inhomogeneities in signal intensity across station. This facilitates clinical reading of WBDWI studies as pathological disease show more uniform signal across imaging stations, making it easier to compare findings between stations and between studies. Inter-station signal normalization also facilitates disease segmentation based on the signal intensity of disease on DWI. [4]. However, minor residual discrepancies between stations may still occur, especially when acquiring thicker image slices, as a consequence of the primary assumption by our algorithm, i.e. that the images either side of the station boundary contain the same information. In such cases, ensuring that there is at least one slice overlap in all acquired stations could further refine the algorithm.

**References:** [1] Takahara *et al.*, Radiat Med 2004; 22(4):275-82, [2] Ballon *et al.*, NMR Biomed 2000; 13:321-28, [3] Li *et al.*, J Magn Reson Imaging 2007; 26(4):1139-44, [4] Blackledge *et al.*, Proc 19<sup>th</sup> Annual Meeting ISMRM 2011, 2560.

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