Improved distortion correction in cerebral and spinal DTI using interleaved reversed gradients

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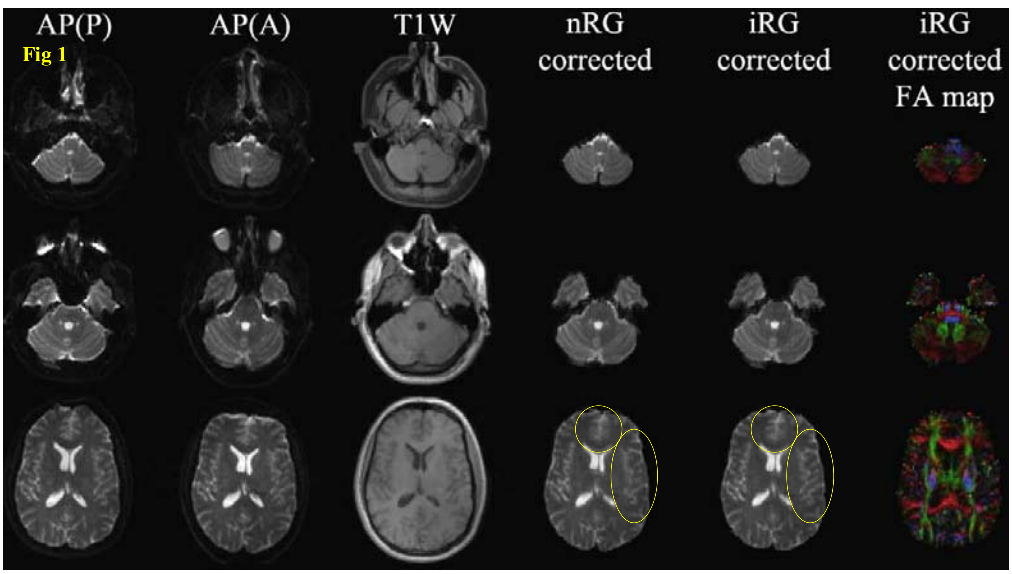
Introduction: Diffusion tensor imaging (DTI) is an important tool for the characterization of normal and pathological tissue. Echo-planar imaging (EPI) is generally used to minimize acquisition time. However, due to the long echo train length of EPI, B_0 field inhomogeneity and eddy currents, EPI-based DTI suffers from susceptibility-induced geometric and intensity distortions especially in the phase encoding direction. Images appear stretched or compressed, which subsequently induces inhomogeneous signal intensity, all of which necessitate correction. Different distortion correction methods have been proposed. In this study, we evaluated the reversed gradient (RG) method[1-4]. The principle of the RG method is to use two data volumes with different phase encoding polarities. A displacement map is then derived directly from the spatial distortion produced. The advantage of RG is that data which is lost in the compressed area can be partially recovered. Also, there is no need to unwrap the phase resulting from conventional B_0 field mapping. However, the RG method is susceptible to subject motion because of the time lag between acquisitions. Also, it is affected by tissues outside the region of interest. All of these will cause significant blurring or even inaccurate distortion correction in the non-interleaved RG (nRG) images. In this study, we propose to use interleaved RG (iRG), rigid-body registration and whole brain/spinal cord extraction for the distortion correction. Comparison between the nRG and iRG is made.

Methods: Pulse sequence programming on the 3T Philips Intera was performed for both nRG and iRG to ascertain that the two data volumes were acquired with the same frequency polarity but with different phase encoding polarity. For nRG, the two data volumes were acquired in two separate scans. For iRG, the two data volumes were acquired in the same scan in a volume-interleaved order such that the corresponding slice pair is separated by only one repetition time (TR). The nRG and iRG were applied in cerebral and spinal cord DTI. All studies were approved by the local institutional review board. **Axial cerebral DTI:** DTI on 2 volunteers was acquired with SENSE head coil, Spin echo EPI in 32 diffusion gradients, resolution: 2.2*2.2*2.2mm^3, SENSE factor: 2.5 and TR: 6727ms. Inter- and intra-data 6 degree of freedom rigid-body realignment was performed on each volume. In order to minimize the effect of the tissue outside the brain on the distortion correction, scalp-stripping was performed using Brain Extraction Tool[5]. The displacement map was calculated in nRG and iRG based on the algorithm described[1,2]. In order to avoid the background noise and the high signal artifacts dominating the effect in the displacement map calculation, thresholds and low-pass filters were applied in the displacement calculation process. The intensity correction was then performed accordingly[1,2]. The distortion correction was performed in b=0 (b0) and all the diffusion data volumes. For sub-voxel correction, the data were up-sampled 2 times in the phase encoding direction before the correction. **Axial spinal cord DTI:** one subject was scanned using multi-element whole spine coil, 15 diffusion directions, resolution: 1*1.25*7mm^3 and TR: 4 heart beats (VCG triggered, longest trigger delay). Realignment and spinal cord extraction were performed to get accurate displacement map. The extraction was performed on the diffusion weighted images by thresholding the mean realigned diffusion-weighted images and considering the connectivity and volume of the voxel clusters, which was then dilated to include voxels with partial volume.



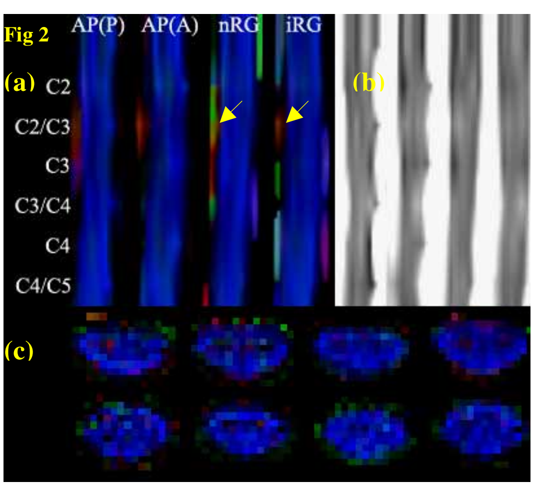


Fig 1: Comparison between anatomical, uncorrected, corrected images of b0 with a FA map by iRG. The phase encoding direction is AP. The letter in bracket is the fat shift direction which is determined by the phase encoding polarity. The circled areas show better gray/white boundaries when iRG was used.

Fig 2: (a) FA and (b) trace maps in sagittal – middle slice and (c) axial views - C4 level (top) and C1 (bottom). Distortion can be seen between C2-C4/C5 in uncorrected images but not in the corrected. iRG achieved better correction results (arrows).

Results: Distortion correction was achieved. Figure 1 shows the uncorrected b0 images, corrected b0 images, iRG corrected fractional anisotropy (FA) map and the corresponding anatomical images of the brain. Figure 2 shows the uncorrected and corrected images of FA and trace maps of the cervical spinal cord in sagittal and axial views. Note that there is different distortion pattern in the cord occurring at the nerve root levels and at the site of intravertebral disk space and can be seen in the uncorrected images. This distortion is accounted for in the corrected images.

Discussion and Conclusions: Our results show that by using iRG, cerebral and spinal cord DTI can be corrected. The shape and intensity in areas like cerebellum, pons, and frontal lobes are satisfactorily restored. When comparing nRG and iRG, clearer gray/white matter boundaries can be obtained in the brain by using iRG (circled areas in fig. 1). In spinal cord DTI, the shape of the cord is corrected such that a smoother spinal cord boundary can be obtained by iRG (arrows in fig. 2a). The improvement is due to the fact that by acquiring the two volumes in an interleaved order, motion between the corresponding slice pair is minimized, which facilitates better realignment. Hence, more accurate displacement map can be obtained. The brain and spinal cord extractions remove tissues outside the region of interest and improve the displacement calculation. Our approach effectively restores the shape and intensity in distorted areas while minimizing the motion effect.

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References: **1.**Voss, H.U., et al., Magn Reson Imaging, 2006. 24(3): p. 231-9. **2.** Morgan, P.S., et al., J Magn Reson Imaging, 2004. 19(4): p. 499-507. **3.** Andersson, J.L., et al., Neuroimage, 2003. 20(2): p. 870-88. **4.** Chang, H., et al., IEEE trans. med. imag., 1992. 11(3): p. 319-329. **5.** Smith, S.M., Hum Brain Mapp, 2002. 17(3) p. 143-155