Diffusion Weighted Imaging of Spinal Tumors with Reduced Field of View EPI

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Introduction: At our institution, there is a great need for diffusion-weighted (DW) and diffusion-tensor (DT) imaging of the spinal cord for the assessment of cord lesions, including tumors, cysts, post traumatic cord contusions, as well as congenital anomalies. While DWI can provide insight into the nature of cord lesions, such as ischemia, infectious or toxic-metabolic processes, neoplasms, and dermoids/epidermoids, the relationship between these lesions and spinal tracts are difficult to define. DTI could further probe biology of the underlying lesion, elucidate integrity and location of the spinal tracts, reveal otherwise occult lesions, and potentially aid in surgical navigation. However, due to the geometric distortion that arises from the slow phase-encoding bandwidth in echo-planar imaging (EPI), our radiologists have largely given up on spinal cord diffusion imaging using conventional single-shot DW-EPI. The zonally oblique multislice (ZOOM)-EPI technique [1-3] is an approach which uses a tilted refocusing pulse to reduce the phase-encoding FOV, thus reducing geometric distortion and image blurring. Here we demonstrate the feasibility of ZOOM-EPI for assessing spinal tumors at 1.5T and 3T. To demonstrate the potential for further improvements in this technique we also present distortion-corrected images acquired on a healthy volunteer at 3T.
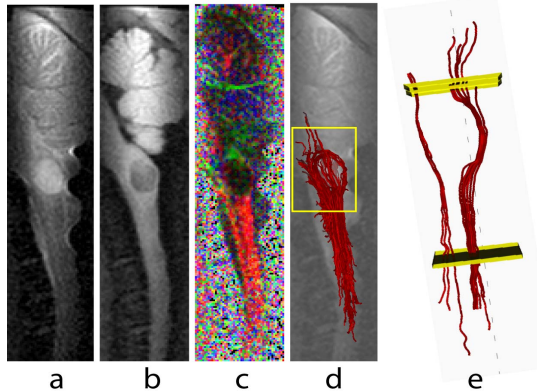

Figure 1: ZOOM-EPI images of a 35 year old patient with a low grade tumor. (a) b = 0, (b) isoDWI, (c) color FA, (d-e) tractography showing that the tumor is well-encapsulated. This was confirmed surgically.

Methods: DTI datasets were acquired on a 1.5T and 3T whole-body GE system. Both magnets used a 4-channel spine coil. ZOOM-EPI DTI datasets were acquired on two patients: a 5 year old male with a suspected thoracic cord neoplasm (3T, FOV = 22cm x 5.5cm, matrix size = 224 x 56) and a 35 year old female with cervicomedullary neoplasm (1.5T, FOV = 18cm x 4.5cm, matrix size = 192 x 48). Imaging parameters common to both patients were: TR = 3s, seven slices with 3mm thickness and no gap, zoom-angle θ = 10º, TE/TR = 73ms/3s, partial Fourier encoding (18 overscans), 5 $b = 0$, 35 isotropically distributed DW directions with $b = 500$ s/mm^2, and a scan time of 2mins. Both patients underwent surgical resection of the tumor, and the tumor grade was evaluated histopathologically. In addition, volunteer cervical and thoracic DTI data were acquired with the same parameters as above (3T, FOV = 22cm x 5.5cm, matrix size = 224 x 56), except that only four $b = 0$ images were acquired, and two of these were acquired with an opposite phase-encoding gradient to enable subsequent distortion correction using the reversed gradient polarity (RPGM) method [4].

Results: The ZOOM-EPI $b = 0$ s/mm^2, isotropic DWI, color fractional anisotropy (FA), and tractography images for the two patients are shown in Figs.1-2. Fig. 1 shows a well-encapsulated tumor, which was found surgically to lack local tumor infiltration and also was confirmed pathologically to be a low-grade tumor (grade I pilocytic astrocytoma). Fig. 2 shows a more aggressive neoplasm with an infiltrative tumor biology where neoplastic cells infiltrate and traverse alongside spinal tracts. At surgery, the lesion was adherent and difficult to completely excise due to its infiltrative nature; pathologic assessment revealed infiltrating grade II astrocytoma, confirming our pre-operative diagnostic suspicion based on ZOOM-EPI data. Fig. 3 demonstrates distortion-corrected ZOOM-EPI data in a volunteer, showing that it is possible to make further improvements to ZOOM-EPI with post-processing.

Discussion: This work shows the application of ZOOM-EPI in a useful clinical setting. Based on the utility of these first patient data acquired at our initiation, ZOOM-EPI DTI data enhanced diagnostic capacity for pathologic tumor grade, and further defined the relationship between spinal tracts and the underlying lesion, an important potential application in surgical management.

There was initially some reservation about the multi-slice capability of ZOOM-EPI given that the tilted slice approach may saturate neighboring slices (and therefore significantly reduce the SNR). However, since the useful anatomical region typically resides in the center of the slice, it is possible to get away with small zoom-angles (10º), and thus reduced saturation effects. Our volunteer experiments have shown that multi-slice ZOOM-EPI only comes at a very small expense of SNR. Other reduced FOV approaches such as spatial-spectral selection [5] do not suffer from this saturation effect, however these approaches have a limited number of slices that can be acquired.
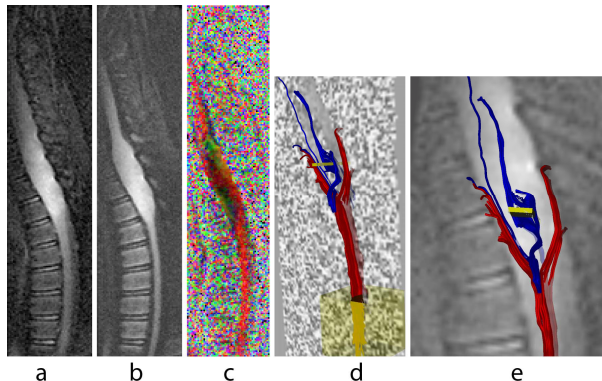
At present, we have limited the FOV to a maximum of 18cm at 3T in order to keep distortions at a reasonable level, but we are encouraged by volunteer data that larger rectangular FOV can be achieved in combination with distortion correction (with the use of an oppositely-acquired $b = 0$ image). Future work will explore a reasonable set of imaging parameters one should use clinically in combination with distortion correction.

Summary: This work demonstrates that spinal cord DTI can be extremely useful for the clinical work up of patients, and that ZOOM-EPI is a useful acquisition method to keep distortions within a reasonable limit. Both patient DTI data acquired at 1.5T and 3T revealed important information. Future work will explore whether additional post-processing to reduce distortion can aid the clinical workup of patients.

no distortion correction / distortion corrected / +ve   -ve   ave.

Figure 3: Thoracic $b = 0$ images (NEX = 2) (top row) No distortion correction. (bottom row) distortion-corrected images produced by using the displacement field calculated from the positive (+ve) and negative (-ve) images. The far right is the average of the positive and negative images.

Figure 2: ZOOM-EPI images of a 5 year old pediatric patient with an aggressive neoplasm. (a) b = 0, (b) isoDWI, (c) color FA, (d-e) tractography depicting infiltrating tracts that were consistent with surgical findings.
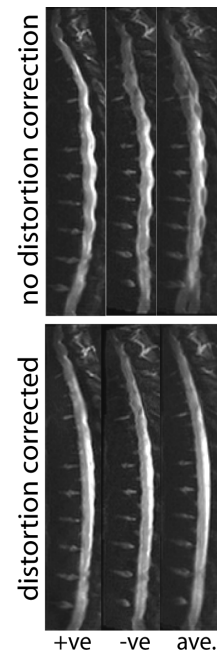
References: [1] Mansfield P. Phys. E: Sci. Instrum. 1988 21:275. [2] Symms M. ISMRM 2000;160. [3] Wheeler-Kingshott, MRM 2002 47:24. [4] Andersson JL. Neuroimage 2003;20(2):870-888. [5] Saritas E. MRM 2008;60:468.