Diffusion Weighted MRI of Spinal Cord Injuries after Instrumented Fusion Stabilization

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Introduction: In 2019, the global incidence of spinal cord injury (SCI) reached almost 900,000 cases, resulting in a significant population facing the challenges associated with such injuries[1]. While magnetic resonance imaging (MRI) has long been a diagnostic tool for SCI, its ability to detail microstructural changes is limited. Diffusion-weighted MRI (DWI) offers more detailed insights at the cellular level, but its effectiveness is compromised in patients stabilized with metallic implants, a common intervention post-SCI. Such metallic stabilization often results in image distortion, especially with standard DWI techniques. However, Multi-Spectral Imaging (MSI) [2,3], which was designed to reduce implant-induced artifacts in MRI, has recently extended its scope to DWI. This study leverages the DW-MSI [4] technique to analyze cord diffusivity in patients with cervical SCI who have undergone cord stabilization using metallic hardware.

Methods: Imaging was performed on 12 SCI subjects and 49 controls, with SCI subjects being imaged between 3 and 18 months after injury. All participants provided written consent within an IRB-approved study protocol. MRI was performed at 3 Tesla, employing commercial isotropic T1 and T2 weighted 3D-MSI for morphological imaging, a prototype DW-MSI sequence [4], and the commercial FOCUS method. Imaging was focused on the C2-C7/T1 cervical spinal cord levels, where all analyzed SCI were located. Images were processed with the Spinal Cord Toolbox [5] to generate cord segmentations, perform vertebral labeling, and register segmentations.

Collected meta-data included sex, age, and body-mass-index. For SCI subjects, American Spinal Injury Association (ASIA) severity and motor symptom scores at injury time were also recorded. Mean cord diffusivity of axial cross-sections was modeled against various covariate and outcome factors, including injury severity and motor function. Statistical analysis utilized Linear mixed-effects models accounting for covariates and random effects.

Results: Figure 1 showcases sample images from a SCI subject. The artifact reduction achieved using multi-spectral imaging techniques is clear when comparing panels (B, conventional) and (C, 3D-MSI). DW-MSI's significance is highlighted in panels (F, FOCUS EPI) and (G, DW-MSI); the cord region is entirely masked by artifacts in the traditional single-shot EPI (F) for all subjects. This consistent issue with FOCUS DWI near the injury site was noted across all participants. Figure 2 provides a representative DW-MSI ADC map of the cord at injury site in the SCI subject from Figure 1. Column (A) depicts magnitude images at b=0, column (B) displays the averaged ADC maps across the entire spine, and column (C) merges the ADC map within the spinal cord ROI and the b=0 magnitude image.

There was a distinct elevation in the ADC measures at the injury levels of SCI subjects when compared against the non-injured levels ($p=0.001$). As time progressed post-injury, a clear decline in ADC values at the injured levels was observed ($p<0.001$). A deeper look into areas below the injury revealed that the ADC values in SCI subjects were noticeably lower than what was seen in control subjects ($p<0.001$). Importantly, the severity of the injury was directly proportional to the magnitude of reduction in ADC values. Lastly, in a preliminary observation with potential clinical significance, ADC measures below the injury were found to be positively correlated with the lower-extremity motor scores ($p=0.012$).

Discussion: The introduction of DW-MSI in spinal cord assessments represents a potential enhancement spinal cord injury research and clinical evaluation. Specifically, the ability to extract reliable DWI data near fusion hardware is novel. The results of this study, specifically the elevated diffusivity at injured levels and its gradual reduction over time, mirror the expected physiological responses to injury. Additionally, the decline in diffusivity below the injury site offers a microscopic perspective into the cascading effects of an injury, potentially affecting areas removed from the primary injury site. The associations drawn between the ADC values and motor scores further underline the clinical implications of the DW-MSI technique, offering potential information that could eventually aid in prognosis and therapeutic decisions.

Significance: By addressing the longstanding issue of metal interference in DW MRI, DW-MSI technique provides an opportunity to explore the post-injury spinal cord microstructural architecture. Though still in its early stages, DW-MSI holds promising potential that could redefine the benchmarks of SCI care, potentially providing clinicians and patients with deeper insights and improved therapeutic strategies. The prospective value of this technology in SCI extends beyond mere diagnosis – potentially assisting in holistic, informed, and targeted care for those with spinal cord injuries. However, further investigative research is crucial to fully understand and harness DW-MSI's capabilities in SCI diagnosis and monitoring.

References: [1] *Ding et al. 2019. Spine 47(21):1532*, [2] *Koch et al. 2009. Magn. Reson. in Med. 61(2):381–390*, [3] *Lu et al. 2009. gn. Reson. in Med 62:66–76* [4] *Koch et al. 2018. gn. Reson. in Med 79(2):987–993*, [5] *Leener et al. NeuroImage 145, Part A (2017) 24-43.*
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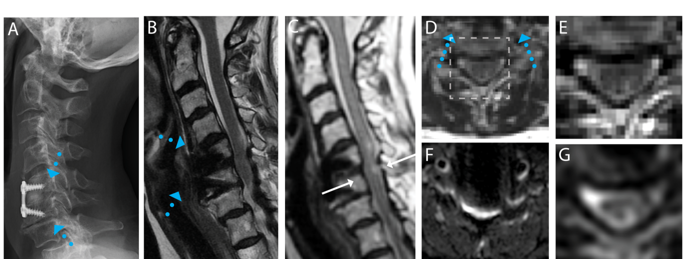

Figure 1: Example images from an SCI study participant. Of importance, note the conventional (F) vs DW-MSI (G) images.

Figure 2: Map of computed ADC within the cord of the subject shown in Figure 1.