

MRI of neural and vascular injury pattern in contusion spinal cord injury

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Introduction

In experimental spinal cord injury (SCI), the proximal and distal vascular disruption is previously reported to contribute to the secondary injury resulting from the intraparenchymal hemorrhage^{1,2}. The early vascular damage and the resulting edema, necrosis, demyelination, cyst formation, and infarction greatly impact the neurological function after SCI. Nevertheless, scarce evidence regarding the role of concomitant distal vascular disruption on the distal white matter injury has been reported. By using diffusion-³ and T2*-weighted imaging⁴, the current study investigated the vascular and white matter injury patterns simultaneously suggesting that the distal white matter injury in contusion SCI correlated with the extent of vascular disruption. However, finding may suggest that vascular damage is not related to the secondary white matter injury in SCI.

Material and Method

Contusion Spinal Cord Injury

T9-contusion was performed on fourteen to sixteen-week-old C57BL/6 mice weighing 25-29 g using a modified Ohio State University (OSU) impactor (tip = 1.3 mm) at a depth of 0.3, 0.5, or 0.8 mm (n = 3 for each injury group). Age and gender matched mice (n = 3) were sham-operated as controls. The injured animals were imaged hyper-acutely (~3 hrs) to evaluate the pattern of white matter and vascular disruption.

MRI

T2*-weighted 3D data sets were acquired using a gradient-echo sequence. Acquisition parameters were: FOV: 11 × 11 × 11 mm³, image matrix = 128 × 128 × 128, TR/TE = 20/6 ms, excitation pulse angle = 20°. In vivo diffusion MRI was acquired by two-direction DWI, (G_x, G_y, G_z) = (1,1,0), (0,0,1), using a multiple spin echo diffusion weighted sequence with 45 slices at 94 μm × 94 μm × 200 μm resolution. Other imaging parameters were: TR/TE= 2000/27 ms, TE2 13ms, Δ 15 ms, δ 5 ms; b-value 0 and 1200 s/mm², FOV 0.9 × 0.9 cm², data matrix 96 × 96 zero-filled to 192×192, and 3 echoes averaged. The total scan time was ~2 hrs.

Results

Three injury severities at mild (0.3 mm), moderate (0.5 mm), and severe (0.8mm) were generated. Compared to the sham-operated controls, all three injury groups displayed obvious white matter injuries in the parallel diffusivity maps and vascular disruptions in the T2*W images (Fig.1). Mild injured group exhibited only local hemorrhage and white matter injury at the epicenter. The moderately injured group exhibited vascular and white matter injury patterns coexisting in the epicenter and significant rostral white matter injury with less prominent but noticeable rostral vascular damage. The severe group displayed a prominent focal hemorrhage and white matter damage both in the epicenter and rostral regions. All white matter injury patterns distributed evenly from the injury epicenter to the distal regions.

Discussions and Conclusions

The neural and vascular injury patterns in the epicenter and distal sites were examined by diffusion- and T2*- weighted images. Distal injury appears to consist of both vascular disruption, but also in the white matter injury. In our recent numerical simulation, we showed that the white matter is more sensitive to the strain rate, which spreads widely along the longitudinal direction. However, the vascular disruption is more related to the focal stress distribution. The acute vascular and white matter damage extended more significantly rostrally. This probably reflects the mechanical stress spreading and implies the acute vascular injury does not contribute to the secondary degeneration of white matter in SCI that extends more severely caudally.

References

1. Nobel et al., Brain Res., 1989, 13 482(1) 57-66; 2. Tator et al., J Neurosurg, 2008, 75:15-26; 3. Loy, et al., J. Neurotrauma 2007, 24: 979-990. 4. Hackney, et al., Radiology 1986, 161: 387-390.

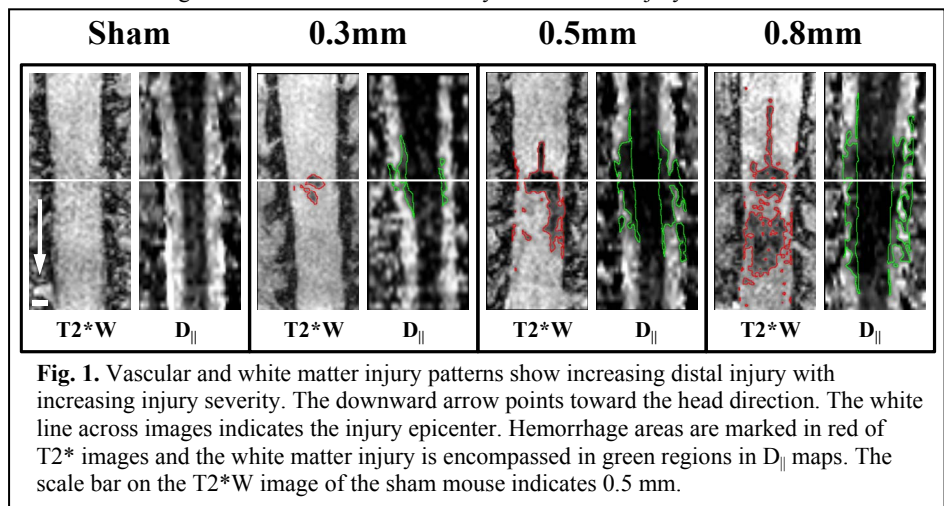


Fig. 1. Vascular and white matter injury patterns show increasing distal injury with increasing injury severity. The downward arrow points toward the head direction. The white line across images indicates the injury epicenter. Hemorrhage areas are marked in red of T2* images and the white matter injury is encompassed in green regions in D_{||} maps. The scale bar on the T2*W image of the sham mouse indicates 0.5 mm.

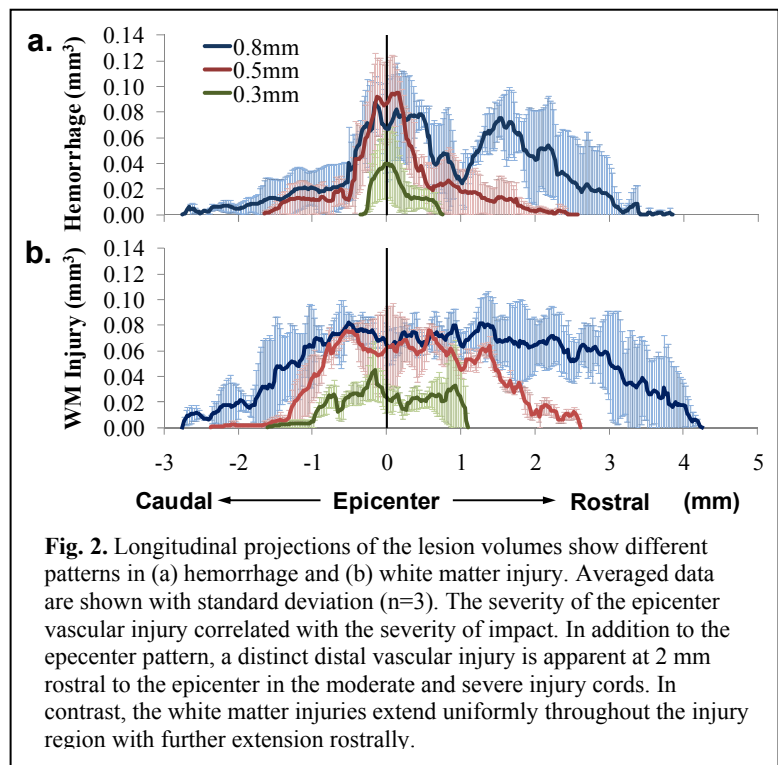


Fig. 2. Longitudinal projections of the lesion volumes show different patterns in (a) hemorrhage and (b) white matter injury. Averaged data are shown with standard deviation (n=3). The severity of the epicenter vascular injury correlated with the severity of impact. In addition to the epicenter pattern, a distinct distal vascular injury is apparent at 2 mm rostral to the epicenter in the moderate and severe injury cords. In contrast, the white matter injuries extend uniformly throughout the injury region with further extension rostrally.