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Experimental Spinal Cord Injury: Imaging the Acute Lesion

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Summary: In order to obtain high resolution images of fixed excised rat spinal cords we have developed a technique using a 6-mm bore, two-turn saddle coil, with a usable imaging length of approximately 4 cm. MR imaging is performed on a prototype 31-cm bore, 1.9-T system with a 1.5-mm section thickness and 7.6-mm field of view.

Index terms: Spinal cord, injuries; Spinal cord, magnetic resonance; Magnetic resonance, technique; Animal studies

Prior magnetic resonance (MR) studies of experimental spinal cord injury have described the relationship between MR imaging and histopathology (1–3). Previous attempts to relate the intensity of injury to the extent of the MR abnormality have not demonstrated a correlation, perhaps because of limitations in the MR technique (2). We report an approach that produces high-resolution images of the fixed, excised rat spinal cord.

Methods

Animal Subjects and Injury

Sprague-Dawley rats were subjected to a standardized weight-drop injury using a modified Allen technique, the details of which have been described previously (4, 5). Anesthesia was provided using 4% chloral hydrate, 0.9 ml/100 g body weight, by intraperitoneal administration. A laminectomy was performed at T-8, and an impounder was placed on the intact dura. A 10-g weight was dropped 2.5, 5, or 15 cm onto the impounder. Control animals were subjected to anesthesia, laminectomy, and impounder placement without weight drop injury.

After injury, or sham injury for the controls, the animals remained under general anesthesia for 4 hours. Each animal was then killed by intracardiac perfusion with normal saline followed by neutral buffered formalin. After this initial perfusion fixation, the spinal column was removed en bloc and placed in formalin. The spinal cord was removed from the spinal column after fixation was complete, approximately 3 days after death. This procedure was followed to eliminate the possibility of damaging the cord during its removal from the spine. The fixed cord has a far firmer consistency than does the fresh tissue; this is particularly important when measurements are to be performed on the specimen. The approach of in situ fixation followed by excision has been used successfully for many years and does not appear to produce artifacts that may be confused with the effects of cord trauma (4, 5).

An approximately 3-cm length of cord, centered over the injury site, was used for imaging. After excision, these cord fragments were stored in neutral buffered formalin. Previous experience has indicated that fully fixed cords may develop curvatures when stored unsupported in formalin specimen jars. Because the narrow bore of the surface coil required that the cord be straight, the cords were stored attached to wooden tongue depressors using small pins placed through each end of the specimen, remote from the injury site.

MR

The fixed, excised cords were imaged on a prototype 31-cm bore, 1.9-T MR system (Oxford Instruments, Oxford) interfaced with both commercial and homemade components. In order to achieve good signal-to-noise ratio from the rat cord, we built a 5-cm-long, cylindrical radiofrequency coil with a 6-mm bore. This series-fed, capacitively coupled coil was made by bending 18AWG copper wire into a two-turn saddle configuration onto a plastic pipette. The desired resonant frequency and input impedance were achieved by soldering on small nonmagnetic capacitors (American Technical Ceramics, Huntington Station, NY) of appropriate value. The usable imaging length is approximately 4 cm. Our gradient coils produced a maximum gradient field of 3 G/cm. The hardware was controlled by a Data General (Westborough, Mass) 8000 series computer originally designed for use with computed tomography.

Two-dimensional Fourier transform spin-echo 1500,500/39 (repetition time (TR)/echo delay) pulse sequences were used. In order to obtain a small field of view on the axial images, a prolonged sampling time was used which was responsible for the relatively long echo delay used for the short-TR images. The TR of 1500 msec was chosen based on previous work showing this to be more than five times the T1 values found in fixed rat spinal cord tissue (6). Contiguous axial images were obtained extending beyond the rostral and caudal limits of the lesion. The axial section thickness was 1.5 mm, the field of view was 7.6 mm, and the acquired in-plane resolution was 0.059 mm with interpolation to 0.029 mm for display. Sagittal images

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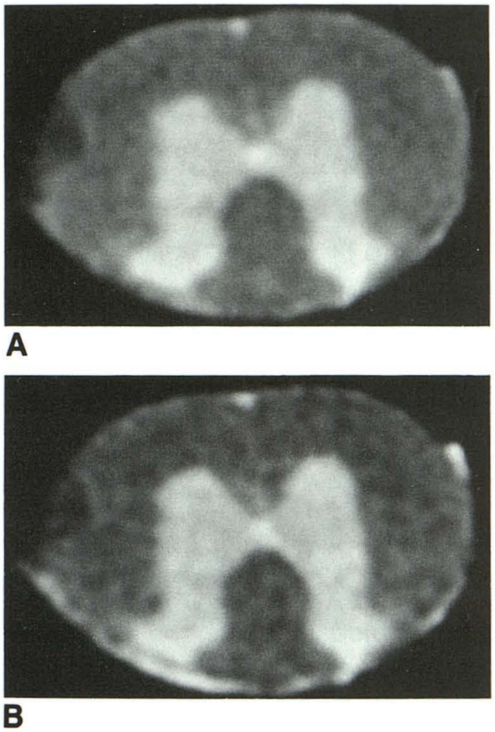

Fig. 1. *A*, 500/39 and *B*, 1500/39 axial images of a control spinal cord. There is excellent differentiation of gray matter from white matter. At this spatial resolution, fiber tracts are not distinguishable.

encompassed the portion of the cord containing the lesion as well as at least 1 cm on either side of the injury site. The field of view for the sagittal images was 3 cm and the section thickness was 3 mm. The rat spinal cord has a small cross-sectional diameter; a single 3-mm sagittal section encompasses all or nearly all of the cord. Sagittal images were used only for positioning the spinal cord.

All images were acquired as multiple section, single-echo studies with selective 180° refocusing pulses. On the axial images, normal gray matter and white matter were identified at levels remote from the injury site.

Results

MR images of a control spinal cord obtained after fixation demonstrate normal gray matter and white matter anatomy (Fig 1). The gray matter has a higher signal intensity than the white matter on the short-TR and on the long-TR images. In the spinal cord T1 and T2 differences between gray matter and white matter are small; mobile proton spin density is the major determinant of image contrast (6). These contrast characteristics are essentially the same in fresh and in fixed tissue (6).

Traumatic lesions were identified as areas of increased white matter signal intensity and an inhomogeneous, mottled appearance (Fig 2). This was associated with a loss of gray-white differentiation in injured segments of the cord. These findings were essentially identical on the short-TR and the long-TR images.

Discussion

These high-resolution images offer the opportunity for more detailed correlations of MR with disease and functional status than have been possible in the past. In particular, this should permit more precise estimates of the severity of pathologic changes that occur in the cord as a result of acute trauma.

References

1. Hackney DB, Asato R, Joseph PM, et al. Hemorrhage and edema in acute spinal cord compression, demonstration by magnetic resonance imaging. *Radiology* 1986;161:387–390
2. Schouman-Claeys E, Frija G, Cuenod CA, Begon D, Paraire F, Martin V. MR imaging of acute spinal cord injury: results of an experimental study in dogs. *AJNR Am J Neuroradiol* 1990;11:959–965
3. Weirich SD, Cotler HB, Narayana PA, et al. Histopathologic correlation of magnetic resonance imaging signal patterns. *Spine* 1990;15:630–638
4. Black P, Markowitz RS, Finkelstein SD, McMonagle SK, Gillespie JA. Models of spinal cord injury: dynamic load technique. *Neurosurgery* 1988;22 (pt. 3):51–60
5. Noble LJ, Wrathall JR. Spinal cord contusion in the rat: morphometric analyses of alterations in the spinal cord. *Exp Neurol* 1985;88:135–149
6. Carvlin MJ, Asato R, Hackney DB, Kassab E, Joseph PM. High-resolution MR of the spinal cord in humans and rats. *AJNR Am J Neuroradiol* 1989;10:13–18

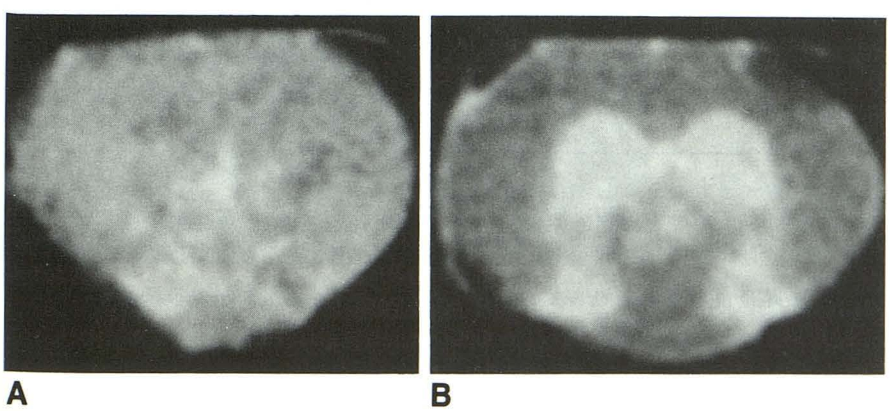

Fig. 2. 1500/39 axial sections through a spinal cord subjected to a 2.5-cm weight drop at the injury site (*A*) and 4.5 mm removed from the epicenter (*B*). At the most severely damaged level, there is nearly complete loss of gray matter–white matter differentiation. At the level adjacent to the injury, there is focal hyperintensity within the dorsal columns.