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Posttraumatic Syrinx Formation: Experimental Study

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An experimental study was performed to examine posttraumatic spinal cord cavitation in an animal model by evaluating immediate and delayed computed tomographic (CT) scans obtained after administration of intrathecal contrast material. Four cats underwent midthoracic laminectomy and spinal cord contusion using a standard 400 g-cm model. All animals were studied by CT with intrathecal contrast enhancement before and 4–5 days, 3–4 weeks, and 7–13 weeks after experimental cord contusion. Either metrizamide or iopamidol was used as the contrast agent. Two of the four cats had CT and pathologic evidence of cord cavitation at the site of injury. Another animal had uptake of contrast material into the spinal cord without pathologic evidence of cyst formation, which was believed to represent malacic change. The fourth animal had a normal-appearing cord by both CT and pathologic criteria. Animals that received metrizamide after cord contusion had generalized myoclonic seizures. This did not occur when iopamidol was administered.

Spinal cord cavitation after serious spinal injury was originally described by Holmes [1] in 1915. In later reports, such patients were characterized by their symptomatology: a progressive ascending myelopathy occurring months to years after a major spinal injury [2–4]. The diagnostic methods used to identify cord cavitation as the etiologic factor varied widely and included Pantopaque myelography [5–7], gas myelography [8], metrizamide computed tomography (CT) without delayed scans [9], and clinical symptoms alone [10]. Two recent reports used CT myelography followed by delayed scans to diagnose cord cavitation in symptomatic patients. In the latter studies, surgical confirmation was obtained [11, 12].

There has been little study of cystic change secondary to spinal cord injury in animals. In one well studied model, a weight is dropped a fixed distance onto the spinal cord after laminectomy [13, 14]. Evaluation of changes in electrophysiologic parameters, neurologic function, and pathologic appearance are commonly performed. Although pathology during the first 24 hr has been well documented [15–20], the pathology of later stages is less well described, with only passing references to cystic change in the spinal cord of rats and monkeys 2 weeks to 2 months after injury [19–21]. There has been no attempt to examine the characteristics of these tissues by CT myelography in correlation with pathologic findings.

The available CT studies of the spinal trauma have been obtained primarily in patients. They show the appearance of acute injury [22–25] and the radiologic documentation of the presence of cavities in the spinal cords of injured patients with diminishing neurologic function [11, 12]. There is a single report of contrast enhancement that was believed to represent contrast-medium collection in malacic tissue rather than a true cavity within the cord secondary to injury [26]. Sonography also has been advocated as a method of documenting cystic change in the cord, either intraoperatively or before surgery if a laminectomy is present [26, 27]. More general reports are not available.

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Fig. 1.—Immediate precontusion metrizamide CT scan at level of laminectomy. Metrizamide surrounds spinal cord shadow. Faint central density (*arrow*) may represent central canal.

Subjects and Methods

Cats who had undergone laminectomy without injury were subjected to a 400 g-cm contusion injury. This has been described in detail [13, 14, 28–33]. In brief, after intravenous barbiturate anethesia and with monitoring of pulse, respiration, blood pressure, and somatosensory evoked potentials, an incision was made in the skin overlying the previous midthoracic laminectomy in order to expose the spinal cord without opening the dura. A 20-g weight was dropped from a height of 20 cm (400 g-cm injury) onto the spinal cord. The incision was closed and supportive care was maintained.

All animals had had laminectomy before the initial CT studies. CT following intrathecal administration of contrast material was performed before and 4–5 days, 3–4 weeks, and 7–13 weeks after injury. Contrast material was instilled under direct vision into the cisterna magna of an animal anesthetized with intramuscular ketamine. After removal of 2 ml of cerebrospinal fluid, either metrizamide (170 mg I/ml) or iopamidol (200 gm I/ml) was placed in the subarachnoid space. One animal received only metrizamide, one only iopamidol, and two animals received both agents in an alternating sequence. CT scans of the spinal axis were obtained on a Philips T60 tomoscanner (120 kV, 300 mA, 9.0 sec scan and 210 FOV, 3.0X zoom reconstruction), within 2 hr of the initial contrast administration and after a 15–18-hr delay. All scans were obtained at both bone and soft-tissue windows.

Sonography was attempted on all cats initially and at 2 months after contusion injury using a 7.5 MHz transducer and ATL real-time equipment.

After the final CT evaluation, the animals were sacrificed. Pathologic evaluation of the spinal cord was made at the injury site using sections stained with hematoxylin-eosin and toluene blue. Correlation was made with the appropriate CT sections both to define the areas of cyst formation and to identify areas of neuronal disruption.

Results

Patterns of contrast enhancement within the spinal cord were evaluated on the immediate and delayed scans. Each animal served as its own control, since the initial series of CT scans was performed after laminectomy but before cord contusion. In two of the four animals on the precontusion immediate (2-hr) CT scans, there was a suggestion of a central density in the cord shadow. This density extended the entire length of the cord and was believed to represent the central canal (fig. 1). This was also present on the immediate study at 5 days in one animal in which a direct injection into the canal might have been performed inadvertently, and in three of the four animals on the immediate scans obtained at 7–13 weeks. The structure was not visualized on any delayed scans. In one animal only, there was a suggestion of cord flattening at 4–5 days after injury. The cord size in the other three animals was unchanged.

Three animals were evaluated at 3–4 weeks. One animal (cat 3) appeared to have a slightly flattened cord on the immediate scan. All three animals appeared to have some increase in contrast in the cord at the contusion site on the delayed scans. In cat 4 the area of increased contrast on the delayed scan was at the edge of the laminectomy, whereas in cats 2 and 3 the contrast collection appeared to be more focal.

All four animals were examined by CT myelography at 7–13 weeks after injury. Each was sacrificed within 3 days after the last CT scan for pathologic examination of the spinal cord. In cat 1, on the immediate scan, which was somewhat marred by motion of the animal, the cord was flattened at the site of the contusion. On the delayed scans there was a dense focal collection at the contusion site, corresponding to the cyst within the flattened cord in the pathologic specimen (fig. 2). In the second animal, there was a dense collection at the level of the cord contusion on the delayed scan, about 1 cm in length. There were also mottled, patchy densities within the cord inferior to the cyst, mainly at the level of the contusion injury. Pathologic examination revealed a large dorsal cyst with surrounding microcysts and demyelination (fig. 3).

The third animal had a patchy region of increased contrast on the right side of the cord at the level of the contusion. The corresponding pathologic specimen demonstrated a wedge-shaped area of demyelination and microcyst formation, which was believed to correspond to the contrast-medium collection visualized by CT (fig. 4). The fourth cat had no abnormal collections of contrast material on the delayed CT scan. Pathologic examination was notable only for the prominent central canal.

Attempts at sonographic examination were unsuccessful because the available probe head was larger than the window provided by the laminectomy defect. Unequivocal identification of cavitation within the cord or of the prominent central canal was not possible.

Generalized myoclonic seizures were noted when metrizamide was present in the subarachnoid space of the injured animals. This was not true in the uninjured animals or in the animals who received iopamidol. This effect had not been anticipated, and electroencephalographic monitoring was not performed. Cat 1, with the flattened cord and central cyst, did not walk; both cat 2, with a dorsal cyst, and cat 3, with the area of decreased myelination, walked; cat 4 walked and was almost normal on neurologic examination.

Discussion

This preliminary study was undertaken to elucidate the radiologic characteristics of spinal injury in a standard model

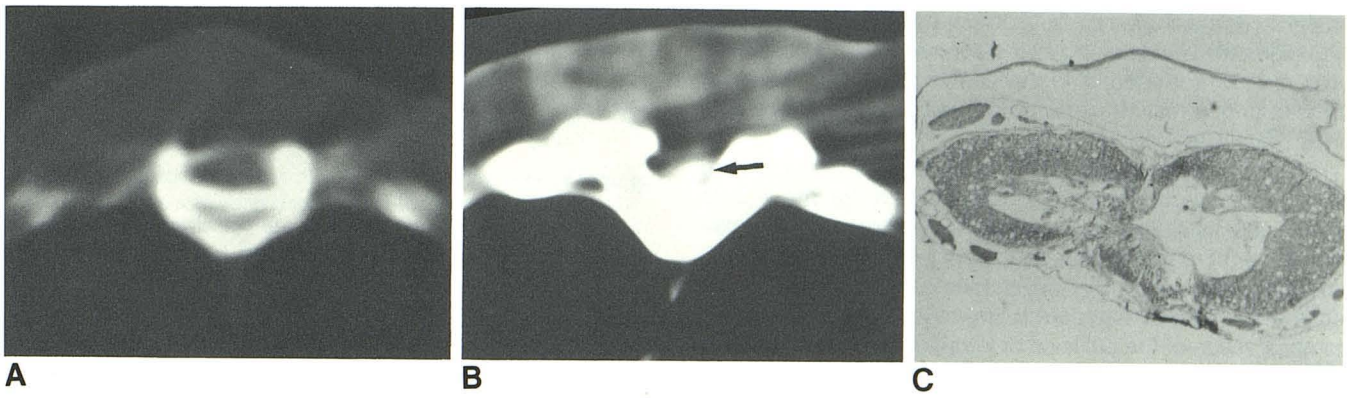

Fig. 2.—Cat 1, 10 weeks after injury. **A**, Immediate metrizamide CT scan at level of contusion demonstrates flattened spinal cord shadow. **B**, 18-hr delayed scan demonstrates dense collection of contrast material (*arrow*) in ventral spinal canal. Corresponding pathologic section (**C**) shows flattened spinal cord with large, irregular cyst.

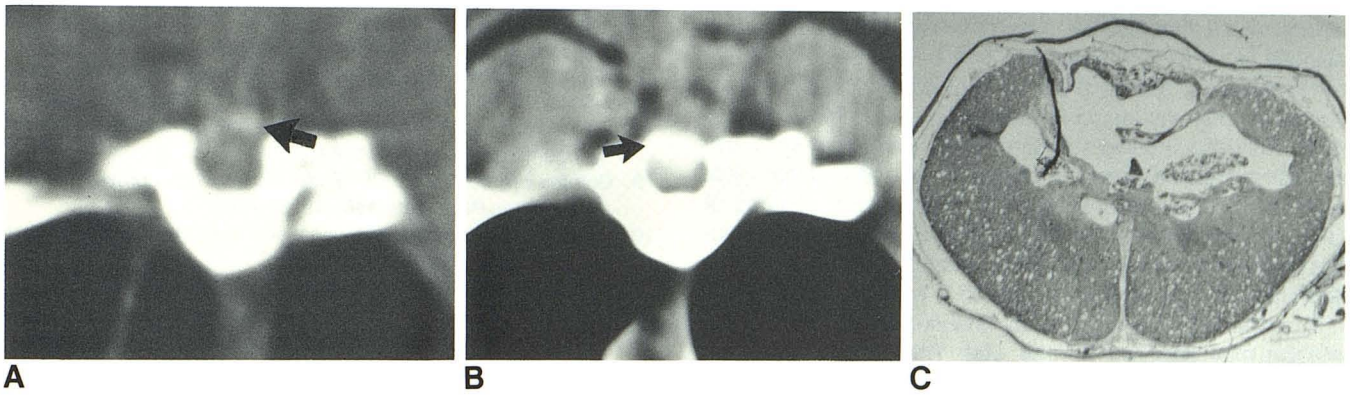

Fig. 3.—Cat 2. **A**, 18-hr delayed scan at 4 weeks after contusion injury. Suggestion of increased contrast in dorsal part of spinal cord (*arrow*). **B**, 18-hr delayed scan at 12 weeks demonstrates large, confluent dorsal collection of contrast material at level of contusion. Corresponding pathologic section (**C**) shows irregular dorsal cystic region.

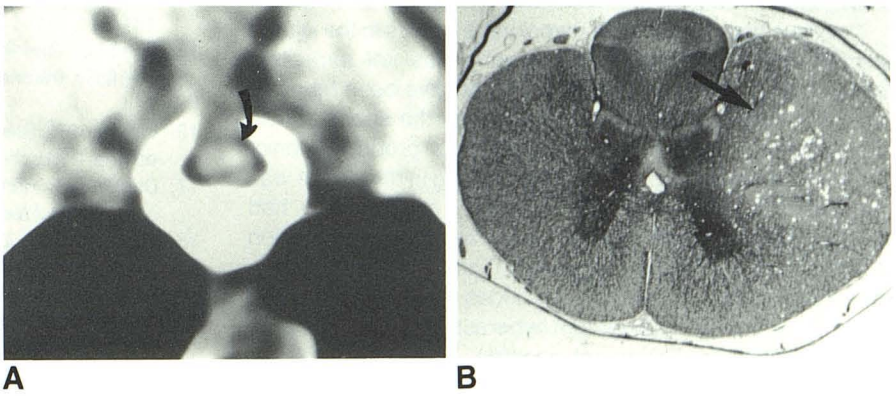

Fig. 4.—Cat 3, 10 weeks after injury. **A**, Delayed metrizamide CT scan at level of laminectomy. Collection of contrast material (*arrow*) at left side of spinal cord. This collection is less dense than that seen in cord with true cavitation. Corresponding pathologic section (**B**) shows wedge-shaped region of poor myelination and microcyst formation (*arrow*) corresponding to region of contrast-medium collection in **A**.

during the first few weeks after contusion injury. Although the number of animals studied was small, the initial results suggest that radiologically diagnosable cystic degeneration of the spinal cord may be common after contusion injury. Two of the four animals had cavities of about 30%–40% of cord diameter at 2–3 months after injury. These cavities were localized to the level of contusion, without significant extension above or below the laminectomy margins, and were demonstrated both on pathologic sections and by delayed CT scans with intrathecal contrast enhancement. Also of

interest, as mentioned by Quencer et al. [26], the delayed CT scans showed areas of increased contrast-medium collection that did not correspond to cavities in the cord. These appeared to be areas of neuronal loss with increased extracellular space and small microcysts.

Gliotic change and neuronal loss as later sequelae of cord contusion have been noted in experimental trauma in cats and monkeys [19, 20]. In areas of pathologically normal-appearing cord there is a suggestion of slightly increased contrast (as in cat 3). This suggestion of diffusion of a lesser amount of contrast material into normal tissue may be similar to observation of the diffusion of intrathecal contrast material into normal brain.

An attempt was made to examine the CT attenuation within the cord, both initially and on the delayed scans, to provide a more rigorous criterion for identifying a cyst. The main difficulty lay in beam-hardening artifacts. The presence of surrounding intrathecal contrast material and/or differing amounts of bone caused variation in attenuation values, which precluded either comparisons of attenuation values longitudinally within the cord or comparisons between early and delayed studies. The spinal cord of the cat was at the limits of resolution of the scanner, so that correction for visually apparent small variations in attenuation value from pixel to pixel was difficult using standard region-of-interest software. All delayed scans were performed at 15–18 hr after initial contrast injection because there was insufficient clearing of subarachnoid contrast on the scan at 8 hr to provide diagnostic studies. This is somewhat later than the recommendations for similar studies in humans [11, 12].

Examination of the spine by magnetic resonance (MR) imaging may supplant CT [34, 35]. The exact role of MR imaging has yet to be defined. Nevertheless, there will continue to be CT studies of patients with intrathecal contrast enhancement; moreover, in the chronically injured patient with metallic stabilization devices, MR imaging may be contraindicated. Early findings suggest that delayed CT using intrathecal metrizamide, in addition to defining the gross anatomy of the cord and demonstrating areas of cystic change, may give an indication of the extent of malacic change.

The development of visible myoclonic seizures in the injured animals with metrizamide myelography was not expected. Seizures and increased electrical activity have been reported in animals after metrizamide injection into the subarachnoid space [36–38]. In addition, ketamine has produced tonic-clonic movements in some patients. Striking in this series was the limitation of this reaction to those animals who had multiple doses of metrizamide; there was no similar reaction in the animals studied with iopamidol. The absence of electroencephalographic monitoring precludes detection of lower levels of central-nervous-system hyperactivity in animals without frank seizures. It was not possible, on the basis of this limited study, to separate the effect of multiple exposures to metrizamide from the effect of injury per se.

In conclusion, in this preliminary study of a feline cord contusion model, two of four animals demonstrated cavities within the spinal cord that corresponded to 30%–40% of the cord diameter both on delayed CT scans with intrathecal contrast enhancement and on corresponding pathologic sections. Collections of contrast material were noted also in areas pathologically confirmed to be areas of neuronal loss, suggesting that further exploitation of CT to evaluate extent of neuronal loss might be of value.

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