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Sequential MR studies of cervical cord injury: correlation with neurological damage and clinical outcome

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In patients with acute traumatic cervical spinal cord injury, it is difficult to make a precise diagnosis of the main site of the injury, the severity of cord damage, and the prognosis of neurological complications

Objective: To determine which images provide the most useful information and the best time to perform prognostic MRI.

Design: The severity of neurological complications was assessed using the ASIA impairment scale. MRI was first performed within 48 h of injury, and was subsequently performed after 2–3 weeks, 3 months, 6 months, and 1 year.

Setting: Inpatient SCI medicine unit.

Subjects: Seventy-five patients with acute traumatic cervical spinal cord injury (9 women and 66 men) aged from 19–89 years (mean: 54.7 years).

Results: Four characteristic patterns of signal changes were observed on MRI. These patterns correlated well with the severity of spinal cord damage and the clinical outcome.

Conclusion: T2-weighted images provided the most useful information, and the best times for prognostic imaging were at the time of injury and 2–3 weeks later.

Keywords: cervical cord injury; magnetic resonance imaging

Introduction

It is difficult to make a precise diagnosis of the main site of injury, the severity of spinal cord damage, and the clinical outcome of neurological complications in patients with acute traumatic cervical spinal cord injury. We conducted a prospective study to clarify these points, and to determine which types of images offer the most useful information and the best time to conduct prognostic MRI.

Materials and methods

The subjects were 75 patients with acute cervical spinal cord injury. There were 66 men and 9 women. The age at injury ranged from 19–89 years (mean: 54.7 years). Paralysis at the time of injury was graded as A in 22 patients, B in 32, C in 16, and D in 7 based on the ASIA impairment scale[1] and IMSOP International Standards.[2] Fifty-five of the patients had no spinal fracture or dislocation, while 20 had bony injuries of the cervical spine. All patients were treated conservatively. MRI was first performed within 48 h of injury, and was subsequently performed after approximately 3 weeks, 3 months, 6 months, and 1 year. Images were obtained using a 1.5 tesla superconducting MR scanner with a surface coil. T1-weighted images were obtained with an echo time (TW) of 17 ms and a pulse repetition time (TR) of 550 ms, while T2-weighted images were obtained with a TE of 130 ms and a TR of 3200 ms. The spin-echo (SE) technique was used and the slice thickness was 5 mm.

Results

Characteristic MRI findings, serial signal changes and correlation with the clinical features

Four characteristic patterns of signal change were observed on MRI (Figure 1). Pattern 1 (ten patients) was characterized by the absence of any signal change on either T1 or T2-weighted images throughout the clinical course. Nine of these patients had no bony injury, while one had cervical spine damage. All patients in this group complained of transient muscle weakness in the fingers, arms, and legs along with numbness and dysesthesia. These symptoms almost completely resolved within 2 months of injury, so the patients were assumed to have suffered spinal concussion.

In pattern 2 (25 patients), there were no signal changes on T1-weighted images from the acute to the chronic stage. However T2-weighted images initially showed an indistinct high intensity area that gradually became localized to the main site of spinal cord injury and almost completely disappeared after 2–6 weeks.

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Twenty-two of these patients had no bony injury, while three had cervical spine damage. Signal changes of this type were observed in patients with central cord paralysis. There was satisfactory resolution of motor paralysis, but residual finger dysfunction was evident in 15 patients and 22 complained of numbness in the fingers at 1 year after injury (Figure 2).

Pattern 3 (30 patients) was characterized by the absence of signal abnormalities on T1-weighted images at the time of injury followed by the appearance of a circumscribed low intensity area at 3–6 weeks after injury. An extensive high intensity area was observed from the acute to subacute stages on T2-weighted images, and this area decreased in size and became more distinct approximately 3 weeks after injury (Figure 3). Seven patients had associated cervical spine damage, while 23 had no bony injury. Most of these patients had more severe neurological deficits than those in patients exhibiting patterns 1 or 2.

Pattern 4 (10 patients) was characterized by a small low intensity area within an extensive high intensity area on T2-weighted images, with no signal changes on T1-weighted images at the time of injury. This low intensity area disappeared and a high intensity area became more distinct on T2-weighted images at 2 weeks after injury. Three months after injury, the high intensity area then became more extensive on T2-weighted images, and a low intensity area was observed on T1-weighted images. The areas of signal

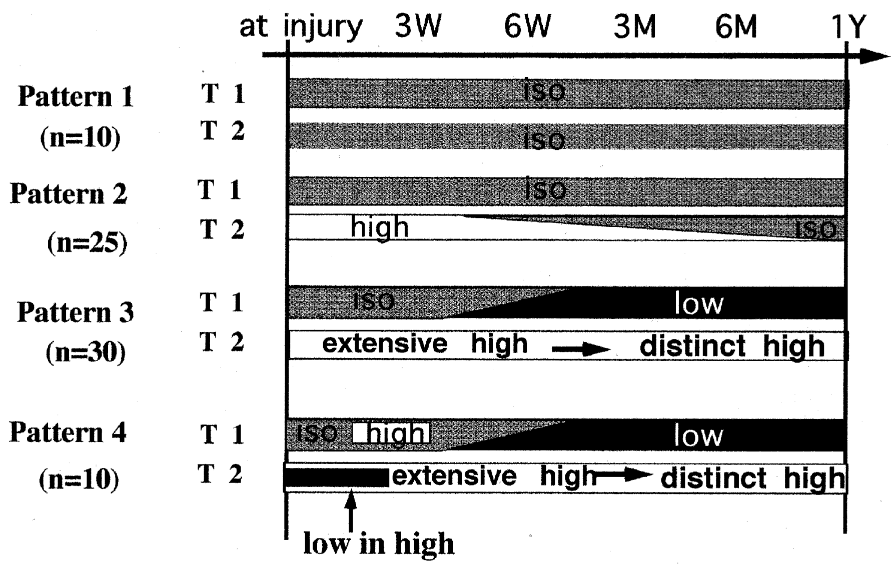

Figure 1 Characteristic MRI findings and serial signal changes

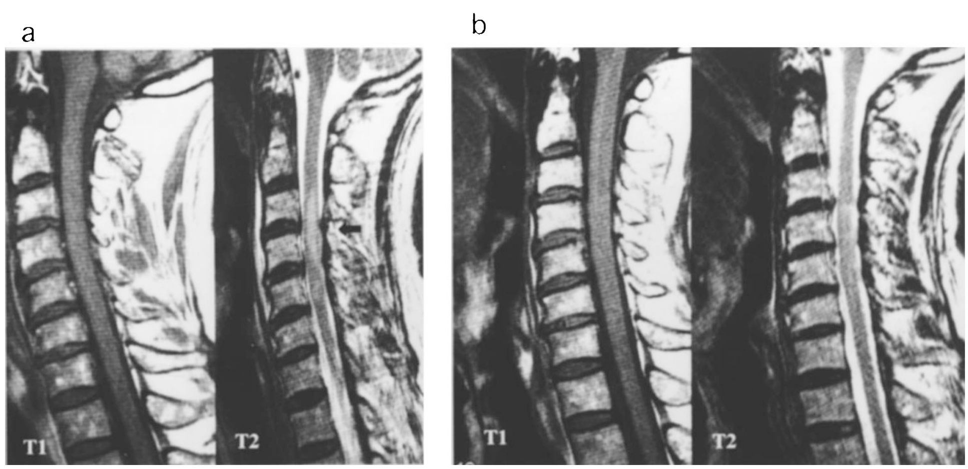

Figure 2 A 64-year-old man. Paralysis was grade C in the acute stage and recovered to grade D by 12 months after injury. (**a**) MRI at 48 h after injury. T2-weighted images showed an indistinct high signal intensity area (black arrow). (**b**) MRI at 4 weeks after injury. The high signal intensity area had almost disappeared. There were no signal changes on T1-weighted images from the acute to the chronic stage

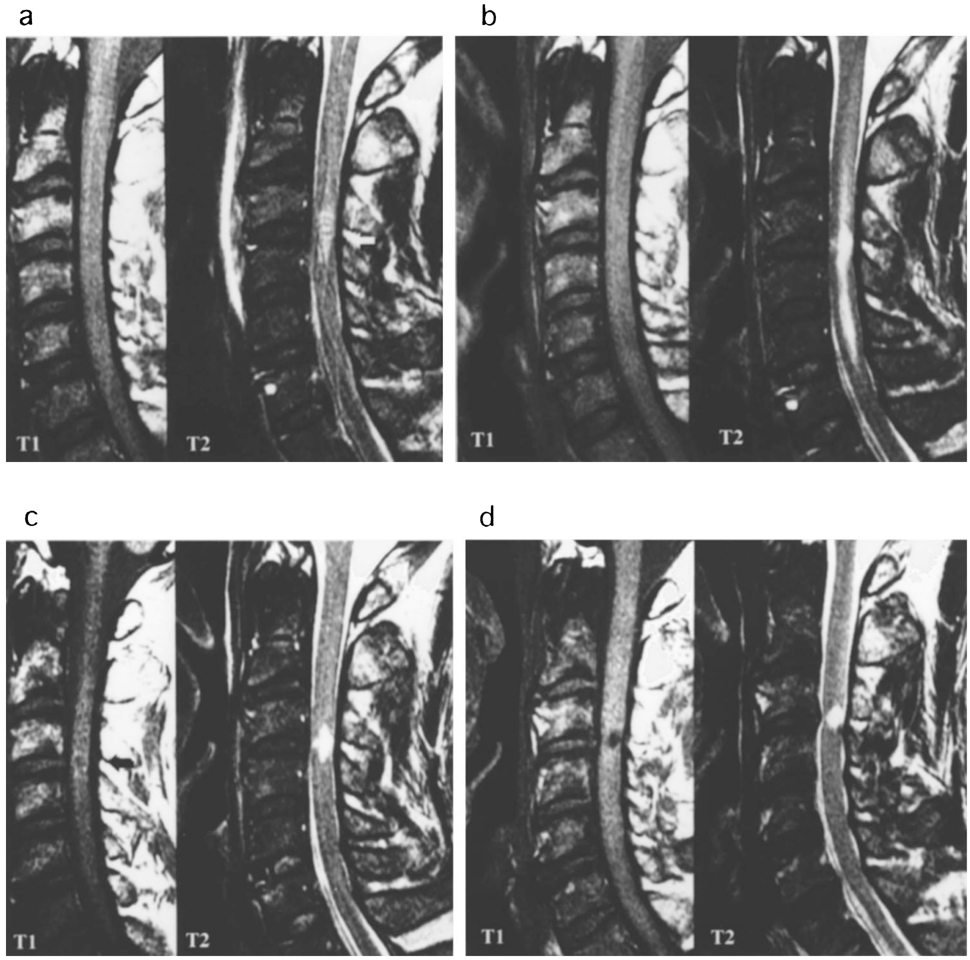

Figure 3 A 35-year-old man. Paralysis was grade B in the acute stage and recovered to grade D by 12 months after injury. (**a**) MRI at 14 h after injury. T2-weighted images showed an extensive and indistinct high signal intensity area at the C3–4 disc level (white arrow). T1-weighted images showed no signal changes. (**b**) MRI at 3 weeks after injury. An extensive and distinct high signal intensity area was observed on the T2-weighted image, and T1-weighted images showed no signal change. (**c**) MRI at 5 weeks after injury. A clear and well-defined high signal intensity area was observed at the C3–4 disc level on T2-weighted images. T1-weighted images showed a circumscribed low intensity area at the same level (black arrow). (**d**) MRI at 6 months after injury. The signal changes were more distinct on both T1 and T2-weighted images

change gradually decreased in size and became more distinct. Atrophy of the damaged spinal cord was evident at 1 year after injury (Figure 4).

Nine patients had associated cervical spine damage and only one patient without bony injury showed these changes. Nine patients had grade A and one patient had grade C Brown-Sequard type paralysis at the time of injury.

Location of the main site of spinal cord damage in the patients without bony injury

The most common site of spinal cord damage detected by MRI in the 55 patients without bony injury was at the C3–4 disc level. The main change in signal intensity was observed at this level in 29 patients (52.2%), while it was at C4–5 in nine and at C6–7 in three. The signal intensity did not change in five patients.

Correlation between MRI signal changes and clinical outcome (Figure 5: Table 1)

The patients showing patterns 1 and 2 generally recovered well from paralysis. Patients with pattern 3 and 4 did not recover as well, but eight of these patients with grade B paralysis at the time of injury recovered to grade D and could walk without assistance 6 months after injury. Six patients (A5, B1) with the main signal intensity change at the C3–4 disc level underwent tracheostomy within 72 h of injury. This was followed by mechanical ventilation in five patients and weaning after 10.4 weeks on average.

Discussion

A clear picture of the location, extent, and severity of traumatic cervical cord injury can be obtained with MRI, which also reflects the histological features of

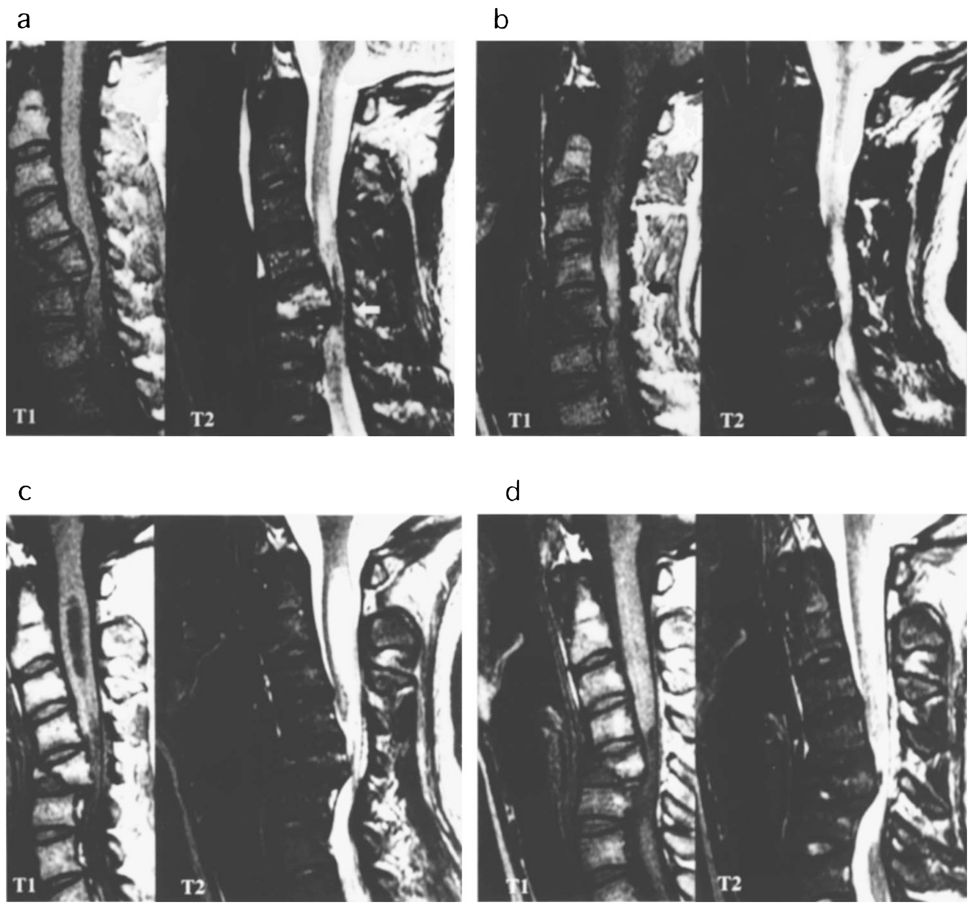

Figure 4 A 19-year-old woman. Paralysis was grade A at the time of injury and showed no improvement. (**a**) MRI at 14 h after injury. A small low signal intensity area (white arrow) within a high signal intensity area was observed on T2-weighted images, while no signal changes were observed on T1-weighted images. (**b**) MRI at 2 weeks after injury. The low intensity area had disappeared and a high intensity area had become more distinct on T2-weighted images. An indistinct high signal intensity area was observed on T1-weighted images. (**c**) MRI at 3 months after injury. The high intensity area was more extensive on T2-weighted images, and a low signal intensity area was observed on T1-weighted images. (**d**) MRI at 1 year after injury. The areas of signal change had decreased in size and had become more distinct

Table 1 Summary of the clinical outcome

	Clinical outcome
Pattern 1 ($n=10$)	resolved (10 cases)
Pattern 2 ($n=25$)	resolved (2 cases)
	motor resolved (22 cases)
	deficit remain (1 case)
Pattern 3 ($n=30$)	motor resolved (9 cases)
	deficit remain (7 cases)
	deficit unchanged (14 cases)
Pattern 4 ($n=10$)	motor resolved (1 case)
	deficit unchanged (9 cases)

intramedullary lesions. MRI of spinal cord injury has been investigated in several previous studies.[3–7] In the present study, the most common MRI pattern was no change in signal intensity on T1-weighted images and a high intensity area on T2-weighted images in the acute stage. This high intensity area on T2-weighted images became isointense (Figure 2) or else became more intense, and a low intensity area began to appear on T1-weighted images in the subacute and chronic stages (Figure 3). Based on previous findings of histopathological features of spinal cord injury,[8–11] a blurred high intensity area on T2-weighted images in the acute stage is thought to represent edema or petechial hemorrhage, while a more distinct high intensity area on T2-weighted images combined with a low intensity area on T1-weighted images during the subacute and chronic stages is thought to demonstrate necrosis, myelomalacia, or an intramedullary cyst. Accordingly, the presence of a high intensity area on T2-weighted images obtained 2–3 weeks after injury appears to be indicative of a permanent neurological deficit (Figure 3b). In the present study, all of the patients exhibiting this signal pattern had neurological deficits of varying severity at 1 year after injury (Figure 5: pattern 3,

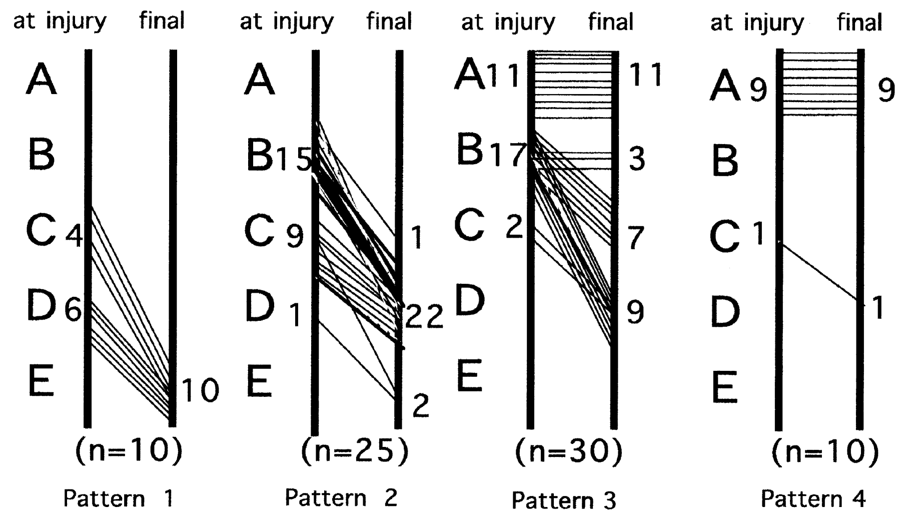

Figure 5 Correlation between MRI signal changes and clinical outcome

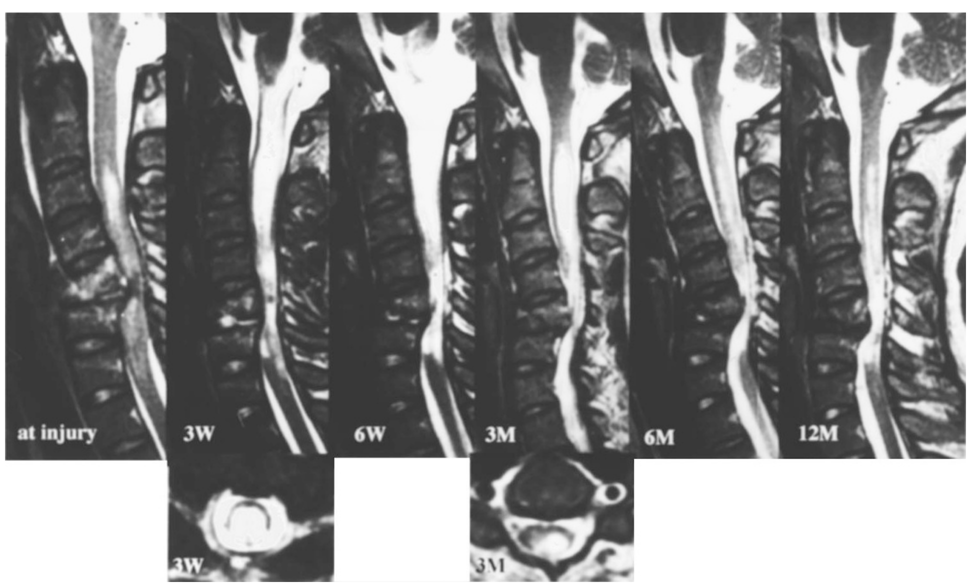

Figure 6 A 19-year-old woman. Paralysis was grade A. MRI showed the signal changes which suggested the pencil-shaped softening of the cervical cord

Table 1). A low intensity area on T2-weighted images in the acute stage is thought to indicate more extensive intramedullary hemorrhage and is attributed to deoxyhemoglobin (Figure 4a).[6,7,12,13] Its presence has been reported to suggest a poor prognosis for neurological recovery.[4,14,15] In our patients, nine of the ten patients exhibiting this low signal change had grade A paralysis from onset to 1 year after injury (Figure 5: pattern 4). Two of these patients complained of increasing pain and numbness in the arms and fingers, and showed a reduction in diaphragmatic movement at 3 weeks after injury. Examination of these patients suggested that their paralysis had extended in the cephalad direction, but it returned to the original level after two months. MRI showed increasing signal change extending cephalad from the main site of injury at the same time (3 weeks after injury) as the patients began complaining of worsening paralysis. This signal change subsequently decreased in magnitude and intensity before converging on the postero-lateral area of spinal cord. One year after injury, signal changes suggestive of syringomyelia were observed (Figure 6). It was speculated that these signal changes may represent pencil-shaped softening of the cervical cord. Several authors have discussed the cause of pencil-shaped softening after traumatic spinal cord injury and its correlation with a traumatic syrinx in the damaged spinal cord, but the exact relationship remains unclear.[16–18]

Use of MRI allows for more precise diagnosis and more effective treatment of patients with traumatic cervical cord injury. It is clear that T2-weighted images provide a highly sensitive means of detecting edema and hemorrhage in the acute stage, as well as for assessing the extent of permanent spinal cord damage in the subacute stage (Figures 3 and 4). Our findings suggest that T2-weighted images are the most useful for showing the detailed anatomy of the damaged spinal cord, and that the best times for prognostic MRI examination are at the time of injury and 2–3 weeks later.

Conclusion

Sequential MRI was performed prospectively in patients with traumatic cervical spinal cord injury. Four patterns of signal change were observed depending on the severity of spinal cord damage. These signal changes provided useful information for predicting the neurological outcome. T2-weighted images provided the most useful information, and the best times for prognostic imaging were at the time of injury and 2–3 weeks afterward. The MRI findings and clinical course suggestive of pencil-shaped softening of the spinal cord were also presented.

References

1 Ditunno JF, Young W, Donovan WH, Greasey G. The international standard booklet for neurological and functional classification of spinal cord injury. *Paraplegia* 1994; **32:** 70–80.
2 Maymard FM *et al*. International standards for neurological and functional classification of spinal cord injury. *Spinal Cord* 1997; **35:** 266–278
3 Hackney DB *et al*. Hemorrhage and edema indicate spinal cord compression: demonstration by MR imaging. *Radiology* 1986; **161:** 387–390.
4 Sato T *et al*. Prognosis of cervical spinal cord injury in correlation with magnetic resonance imaging. *Paraplegia* 1994; **32:** 81–85.
5 Chakeres DW *et al*. MR imaging of acute spinal cord trauma. *AJNR* 1987; **8:** 5–10.
6 Kulkarini MV *et al*. Acute spinal cord injury: MR imaging at 1.5 T. *Radiology* 1987; **164:** 837–843.
7 Flanders AE *et al*. Acute cervical spine trauma: Correlation of MR imaging findings with degree of neurological deficit. *Radiology* 1990; **177:** 25–33.
8 Fujii H, Yone K, Sakou T. Magnetic resonance imaging study of experimental acute spinal cord injury. *Spine* 1993; **18:** 2030–2034.
9 Oshio I *et al*. Correlation between histopathologic features and magnetic resonance images of spinal cord lesion. *Spine* 1993; **18:** 1140–1149.
10 Tanaka J, Shingu H. Neuropathology of spinal cord injury and its pathogenesis. *Rinsho Seikeigeka* 1991; **26:** 1137–1144.
11 Weirich SD *et al*. Histopathological correlation of magnetic resonance imaging signal pattern in a spinal cord injury model. *Spine* 1990; **15:** 630–638.
12 Hackney DB *et al*. Haemorrhage and edema in acute spinal cord compression: demonstrating by MR imaging. *Radiology* 1986; **161:** 387–390.
13 Gomori JM *et al*. Intracranial hematomas: Imaging by high-field MR. *Radiology* 1985; **157:** 87–93.
14 Bondurant FT *et al*. Acute spinal cord injury: A study using physical examination and magnetic resonance imaging. *Spine* 1991; **15:** 161–168.
15 Mori A *et al*. Magnetic resonance imaging of cervical cord injury. *Rinsho Seikeigeka* 1991; **26:** 1163–1171.
16 Kume A, Hashizume Y. Pencil-shaped softening of the spinal cord. *Sekitui Sekizui* 1994; **7:** 191–197.
17 Hashizume Y *et al*. Pathological study of sylingomyelic and pencil-shaped softening of the spinal cord. *Spinal surgery* 1990; **4:** 31–38.
18 Muramatu T, Kikuchi S, Watanabe E. Spinal cord pencil-shaped softening: Comparison between the finding and the autopsy finding. Case report. *Paraplegia* 1994; **32:** 124–127.