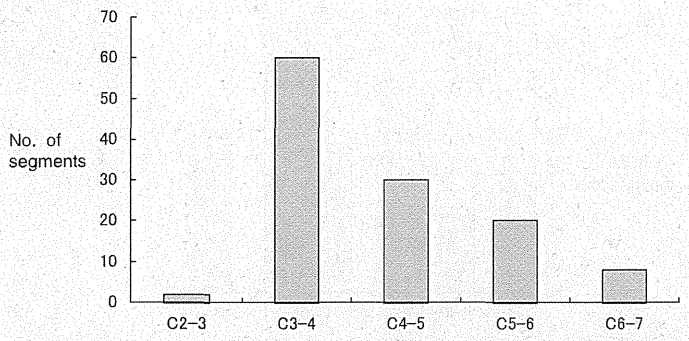

Figure 2. The cervical segment that was suspected to be injured was examined by magnetic resonance image (the site of spinal cord intensity change and/or the apparent discoligamentous damage). C3–C4 was the most frequently injured segment.

follow-up. The average follow-up period was 6 months (range, 1–17 mo) after trauma. All neurological evaluations were done by spinal surgeons.

The relationship between each MRI finding and segmental instability was analyzed using the χ^2 test. Comparisons of the ASIA motor scores among patients regarding the presence/absence of each MRI finding and segmental instability were performed using Student *t* test. The relationships between the ASIA motor scores and either the area of prevertebral hyperintensity or the spinal canal diameter of the injured segment were analyzed using Pearson product moment correlation coefficient (*r* value). All data were analyzed using the JMP 8.0.2 software program (SAS Institute Inc., Cary, NC) and significance was set at 5%.

RESULTS

MRI Findings

The levels of SCI determined on the basis of cord signal change or apparent discoligamentous injuries on MR images are shown in Figure 2. C3–C4 was the most frequently injured segment, followed by C4–C5 and C5–C6. Among the 88 patients, ALL disruption and intervertebral disc disruption were identified in 44 patients (50%) and 37 patients (42%), respectively. Prevertebral hyperintensity was identified in 76 patients (86%). The area of prevertebral hyperintensity ranged from 0 cm^2 to 11.5 cm^2 (average, 2.6 cm^2). All patients presenting with either ALL disruption or disc damage were shown to have prevertebral hyperintensity.

Radiographical Findings

Forty-two patients (48%) showed more than 2-mm posterior translation in the neck extension position. Twenty-eight patients (32%) exhibited more than 3.5-mm posterior translation and/or more than 11° angular deformity than in adjacent segments, indicating that about one-third of the patients were considered to have cervical segmental instability, according to the criteria of White *et al.*[28]

Relationship Between MRI Abnormalities and Segmental Instability

As shown in Table 1, among the 44 patients who were demonstrated to have ALL disruption on MR images, 23 patients were shown to have segmental instability, whereas only 5 of the 44 patients without ALL disruption were shown to have segmental instability. Thus, ALL disruption confirmed by MRI was significantly associated with segmental instability as judged by flexion-extension radiographs ($P < 0.001$). A similar association was found between intervertebral disc damages on MR images and segmental instability ($P < 0.01$). The average area of prevertebral hyperintensity in patients who had segmental instability was 4.0 cm^2, whereas that in the patients who did not have segmental instability was 2.0 cm^2. The difference in the area of prevertebral hyperintensity between the 2 groups was significant ($P < 0.001$), thus suggesting that the area of prevertebral hyperintensity reflects the severity of discoligamentous injuries.

Impact of Cervical Soft-Tissue Damage on the Patients' Neurological Status

As shown in Figure 3A, patients in whom ALL disruption was detected on MR images had significantly lower ASIA motor scores than those without ALL disruption on admission and at 1 month after trauma. Similarly, patients showing disc damage on MR images had significantly lower ASIA

TABLE 1. Associations Between Cervical Segmental Instability and MRI Findings of Soft Tissue Damages

		ALL Disruption (No. of Patients)		Disc Damage (No. of patients)		Average Area of Prevertebral Hyperintensity (cm^2)
		+	−	+	−	
Segmental instability	+	23	5	18	10	4.0
	−	21	39	19	41	2.0
		44	44	37	51	

The cervical segmental instability of the injured segment was defined as follows: more than 3.5-mm posterior translation of the superior vertebral body and/or a more than 11° angular difference compared with adjacent intervertebral spaces. The presence of either ALL disruption or disc damage on magnetic resonance image was significantly associated with that of the cervical segmental instability ($P < 0.001$, $P < 0.01$; χ^2 test). The area of prevertebral hyperintensity in patients with segmental instability was significantly larger than that in patients without segmental instability ($P < 0.001$; Student t test).

ALL indicates anterior longitudinal ligament.

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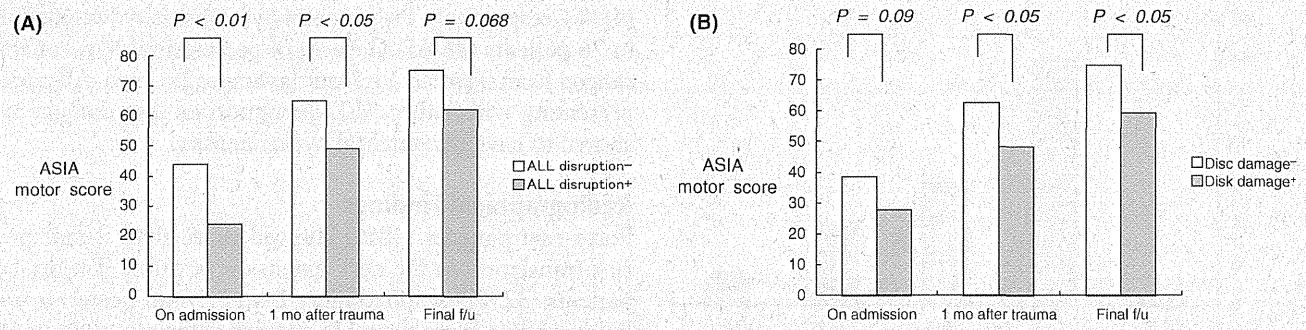

Figure 3. (A) The average ASIA motor score of the patients with or without ALL disruption. A statistically significant difference in the ASIA motor score was seen on admission and 1 month after trauma. **(B)** The average ASIA motor score of the patients with or without disc damage. A statistically significant difference in the ASIA motor score was seen 1 month after trauma and at the final follow-up. ASIA indicates American Spinal Injury Association; ALL, anterior longitudinal ligament.

motor scores than those without disc damage (Figure 3B). In addition, the area of prevertebral hyperintensity had a significant negative correlation with the ASIA motor score, indicating that patients who had larger prevertebral hyperintensity tended to show severe paralysis (Figure 4). All these findings indicate that the soft-tissue damage present at the time of trauma strongly affected the patients' neurological status.

In accordance with these findings, patients showing cervical segmental instability on admission had a significantly lower ASIA motor score at each time point than those without segmental instability (Figure 5).

Relationship Between the ASIA Motor Score and Cervical Canal Diameter

Next, we investigated the relationship between the ASIA motor score and the cervical canal diameter at the injured site to see how cervical canal stenosis affects a patient's neurological status. As shown in Figure 6, there was no relationship between the cervical canal diameter and the ASIA motor score at 1 month after trauma. The same was true of the ASIA motor score on admission and at the final follow-up (data not shown).

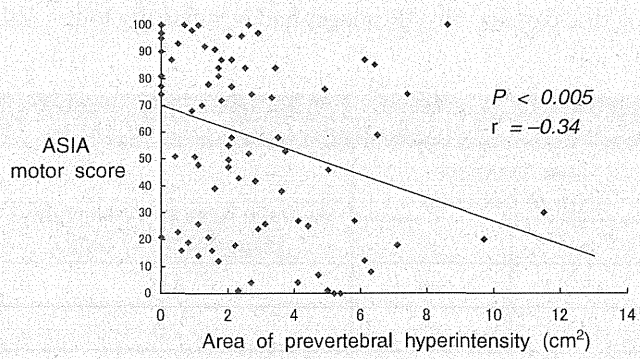

Figure 4. The relationship between the ASIA motor score and the area of prevertebral hyperintensity. There was a significant negative relationship between the 2 parameters, indicating that a higher prevertebral hyperintensity area on magnetic resonance image was associated with more severe paralysis. ASIA indicates American Spinal Injury Association.

DISCUSSION

In patients experiencing acute traumatic cervical SCI without any major bone injury or dislocation on the initial radiographical survey, 2 possible pathomechanisms are thought to be involved; extension-type injury and flexion-type injury (recoil flexion injury). By obtaining careful flexion-extension radiographs at the time of admission, we could exclude patients with spontaneously reduced recoil flexion injury. Therefore, the 88 patients investigated in this study were considered to have sustained neck extension injury. This extension-type cervical SCI can then be further divided into 2 categories. One is patients with pre-existing cervical canal stenosis in whom the spinal cord is compressed between the posteroinferior edge of the vertebra (or protruded disc) and the wrinkled ligamentum flavum in the neck hyperextension position.[7] In this situation, sudden (but physiological) motion of the neck may produce spinal cord compression severe enough to cause SCI without causing any substantial damage to the discoligamentous structures. The other type of hyperextension injury is caused when patients receive more intense neck extension force resulting in various extents of momentary vertebral displacement with discoligamentous injuries. Taylor and Blackwood[6] first described this type of injury as the hyperextension-type "recoil injury," and Harris and Yeakley[11] called this type of injury hyperextension-

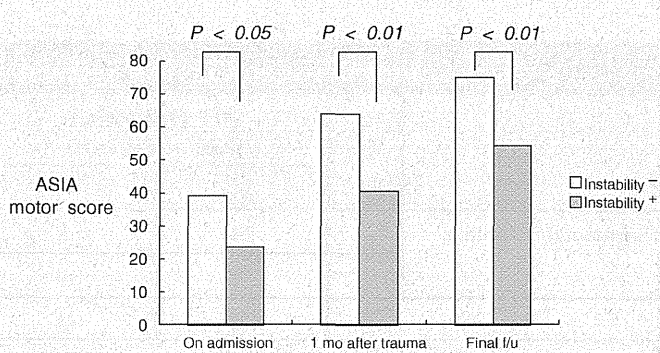

Figure 5. The average ASIA motor score of the patients with or without segmental instability. A statistically significant difference in the ASIA motor score was seen at each time point. ASIA indicates American Spinal Injury Association.

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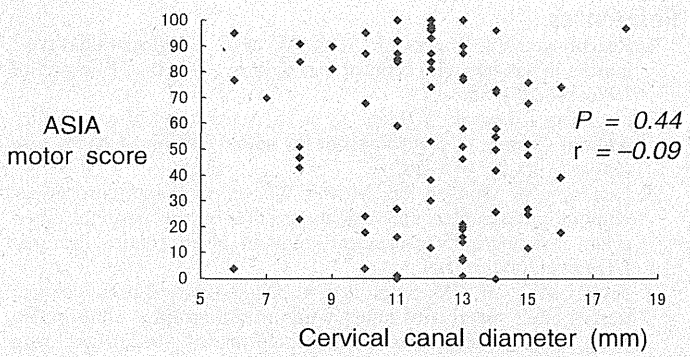

Figure 6. The relationship between the ASIA motor score and the cervical canal diameter at the injured segment. There was no relationship between the 2 parameters, indicating that the severity of the patient's paralysis was independent of cervical canal stenosis. ASIA indicates American Spinal Injury Association.

dislocation without gross displacement on lateral radiographs. In the actual clinical setting, however, there would be many cases in between these 2 categories, and the neurological manifestations would vary from typical central cord syndrome to more severe transverse cord syndrome, depending on the patients' pre-existing conditions and the type of trauma sustained. This heterogeneity concerning traumatic cervical SCI without bony injury is one of the reasons why there has been some confusion about the nomenclature and definition of this type of injury.

For the patients with traumatic cervical SCI without noticeable bony injury on initial radiographs, information on potential discoligamentous injuries and resultant segmental instability, as well as its clinical implications, is important for treatment decision making and the prediction of a patient's prognosis. In this study, we clearly showed that many of the patients without bony injury actually had discoligamentous injuries that were associated with segmental instability. The percentages of patients in whom ALL disruption and disc injury were detected on MR images were 50% and 42%, respectively. These percentages may be underestimated, because it is difficult to accurately identify ALL and/or disc disruptions by MRI. Malham *et al*[29] compared the MRI findings of cervical discoligamentous injuries with surgical findings and found that the sensitivity of ALL and disc injury were only 0.48 and 0.81, thus indicating that only 48% of ALL injuries and 81% of disc injuries detected surgically were evident on MR images. As a result, even more cases with discoligamentous injuries in our study would thus be expected to be difficult to identify by MRI. The fact that 86% of the patients in this study had prevertebral hyperintensity, which was thought to reflect prevertebral fluid collection or hemorrhage due to soft-tissue damage, would support this idea, and it seems plausible that most of the patients with traumatic cervical SCI without any major bone injury experience various degrees of discoligamentous injuries at the time of trauma. The high frequency of prevertebral hyperintensity observed in this study is in marked contrast to previous studies evaluating patients who sustained whiplash injury without paralysis.[30,31] Kongsted *et al*[31] reported that only 3 of 178 patients (1.7%) who had acute neck symptoms without paralysis after a rear end or frontal car collision showed prevertebral edema on MRI. These facts indicate that if there is no prevertebral hyperintensity in the patients with hyperextension neck injury, the amount of extension force applied to the cervical segments at the time of injury is considered to be relatively small, resulting in no or minimal clinical damage to discoligamentous structures. If a patient who sustained neck injury has an apparent neurological deficit but no prevertebral hyperintensity on MRI, it is necessary to carefully re-evaluate the patient's history and neurological status to rule out acute deterioration of pre-existing cervical spondylotic myelopathy.

Obtaining flexion-extension radiographs of the patients with cervical SCI without major bone injury can be completely safe as long as the patients are awake and the physicians handle the patients' neck carefully while watching a C-arm monitor. We have already used this protocol to examine more than 200 patients who did not have major bone injury, and no neurological worsening related to this procedure has occurred so far. The main advantage of obtaining flexion-extension radiographs is not only that it allows us to identify patients with recoil dislocation injury, which would otherwise have been overlooked even with MRI evaluation, but also that it allows us to evaluate less severe cervical segmental instability precisely. We used a part of the criteria of White *et al*[28] (>3.5-mm translation and/or 11° of angulation compared with adjacent segments) for evaluating cervical segmental instability. Their original criteria include other items such as the presence or absence of cord damage, abnormal disc narrowing, positive stretch test, and so forth. Using only a part of their criteria may not be an appropriate manner to evaluate clinical segmental instability. However, the threshold of 3.5-mm translation and/or 11° of angulation were derived from their vigorous experimental studies, and these numbers (3.5 and 11) themselves are considered to have clinical significance. There is currently no better way radiographically to evaluate cervical segmental instability, and all of the patients in our study had varying degrees of cord damages. Therefore, it is a plausible way to use these radiographical criteria for evaluating cervical segmental instability.

By obtaining careful flexion-extension lateral radiographs in the early phase of injury, we could demonstrate that 48% of the patients had more than 2-mm posterior translation of the cephalad vertebral body at the injured segment and 32% of the patients had more than 3.5-mm posterior translation and/or more than 11° of angulation in comparison with the adjacent segments. Considering that patients exhibit some defensive reaction against dynamic neck examination immediately after trauma and because it is difficult for the examiners to ensure that the patients are in the maximum neck flexion and extension positions, it is plausible that there were actually more patients who potentially had initial cervical segmental instability than we identified. Nevertheless, our study clearly demonstrated that the above-mentioned MRI findings of discoligamentous injuries were significantly related to initial cervical segmental instability. Patients with

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either ALL disruption or disc damage on MR images had a significantly higher risk of segmental instability. Furthermore, the area of prevertebral hyperintensity was strongly associated with segmental instability. Of note was the finding that each of these MRI findings, and segmental instability judged by flexion-extension radiographs, had a strong association with the ASIA motor score. In support of this, Song *et al*[32] demonstrated relationship between cervical soft-tissue damage on MR images and presence or absence of SCI in the patients with cervical extension injury. Thus, as more cervical discoligamentous structures are affected at the time of trauma, more spinal cord damage occurs. On the contrary, there was no association between the cervical canal diameter as determined by lateral radiographs and the ASIA motor score. This is in accordance with our previous study of ossification of posterior longitudinal ligament patients with traumatic cervical SCI at C3–C4 level, showing no relationship between the cervical canal diameter of C3–C4 and the ASIA motor score.[33] We recently conducted MRI evaluations on the width of the cervical spinal cord in the patients with cervical SCI without major bone injury and found that there was no relationship between spinal canal compromise as judged by a sagittal view MR image and the ASIA motor score (manuscript in preparation), thus suggesting that the size of the cervical spinal canal has less of a predictive value in evaluating patients' neurological prognosis in the patients with cervical SCI without major bone injury. Taken together, these findings indicate that the severity of paralysis in the patients with cervical SCI without major bone injury mainly depends on the severity of cervical discoligamentous injuries that occur at the time of trauma, and that momentary abnormal displacement of the vertebral body, rather than cervical canal stenosis, is important for determining the patients' prognosis.

In conclusion, this study provides an important perspective concerning the pathophysiology of cervical hyperextension SCI without major bone injury. Eighty-six percent of the patients had varying degrees of prevertebral hyperintensity, and about half of them were shown to have ALL and/or disc injury, both of which were significantly associated with cervical segmental instability. Patients with such discoligamentous insufficiency showed more severe paralysis than those without it, thus suggesting that the severity of paralysis greatly depends on the amount of stress that was given to the injured segment at the time of trauma.

➢ Key Points

- ❑ Eighty-eight adult patients with acute traumatic cervical SCIs without major bone injury were evaluated using MR images and flexion-extension lateral radiographs.
- ❑ A substantial number of patients showed cervical discoligamentous injuries on MRI, which were associated with cervical segmental instability.
- ❑ The patients' neurological status greatly depended on these discoligamentous injuries that occurred at the time of trauma.

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