Spinal cord injury without radiological abnormality in preschool-aged children: correlation of magnetic resonance imaging findings with neurological outcomes

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Object. Spinal cord injury without radiological abnormality (SCIWORA) was defined in the era when magnetic resonance (MR) images were not popularly used as diagnostic tools. Although it is generally accepted that MR imaging can effectively illustrate the level and severity of spinal cord injury in the acute phase of trauma, only a few reports of MR imaging studies of SCIWORA have been published. The authors retrospectively reviewed nine preschool-aged patients with SCIWORA to study the correlation between MR imaging findings and the outcomes of neurological deficits, with an elimination of the bias for age.

Methods. Clinical manifestations, radiological images, surgical records, and MR imaging studies were reviewed. The pre- and postoperative neurological statuses of the patients were reappraised using American Spinal Injury Association scores and Nurick grades. Nonparametric tests were used to analyze the correlations among the variables of patient characteristics, MR imaging appearances of the injured spinal cord, and neurological outcome.

Conclusions. Among the patients with SCIWORA younger than 8 years old, the different patterns of the injured spinal cords could be identified using MR imaging as transection, contusive hemorrhage, traumatic edema, and concussion. The MR imaging patterns of SCIWORA had significant prognostic correlations with the neurological outcomes of these patients; that is, a normal spinal cord appearance was prognostic of a complete recovery of neurological deficits, and intramedullary lesions correlated with permanent deficits with functional disability.

KEY WORDS • spinal cord injury • spine • SCIWORA • magnetic resonance imaging • pediatric neurosurgery

Spinal cord injuries with different vertebral pathological conditions are frequently encountered in Level 1 trauma centers. In young adults (16–45 years old), SCIs are often associated with vertebral fracture. In patients older than 45 years of age, however, they are frequently secondary to spondylotic degeneration, which compromises the spinal canal and predisposes the spinal cord to blunt injuries during excessive spinal motion, as in hyperextension and hyperflexion. From infancy to age 16 years, SCI is rare and it frequently occurs without vertebral trauma.

Now familiar to modern neurosurgeons, SCIWORA was first clearly described as a distinct disease in 1982, when MR images were not commonly used as a diagnostic tool for SCI.57 Despite increasing applications in the modern era, however, MR imaging studies of SCIWORA are few.59,18 Although mainly occurring in the pediatric population, it is evident that neurological deficits and outcomes associated with SCIWORA are much more disabling in children younger than 8 years old than in older children.16,19 In the cervical spine, the phenomenon is generally explained by stating that younger children have weaker paraspinal muscle control, more horizontal positioning of the spinal articular facets, a less developed uncinate process, a more wedge-shaped vertebral body, and a larger-sized head than do older persons.12 In the thoracolumbar spine, the pathogenesis of SCIWORA may be related to the mismatch in the elasticity of the tissue of the vertebral column and spinal cord; that is, the former can endure much longer distraction than the latter during an acute hyperextension or hyperflexion posture in a traumatic episode.12 After the age of 8 years, when Taiwanese children go to elementary school, the morphology and biomechanics of their vertebrae will approach those of adults. Because age has such an important impact on the severity of SCIWORA, it is reasonable to view patients with SCIWORA younger than 8 years old as a distinctive population. Therefore, we performed a retrograde study to review preschool-aged children with SCIWORA, treated at CGMH after 1994, when our hospital began using MR imaging for neurological diagnosis. We emphasized the effect of MR imaging findings in the acute
stage of SCIWORA on long-term outcome prediction in these younger children.

Clinical Material and Methods

Patient Population

Inpatient records at CGMH from January 1994 (when MR images began to be used for clinical diagnosis in our hospital) to July 2004 were collected. Charts and radiographs of preschool-aged children (< 8 years old in Taiwan) were thoroughly reviewed. For selection criteria we used CT scans and Pang and Pollack’s criteria for SCIWORA: an objective, posttraumatic myelopathy without vertebral subluxation or fracture as seen on plain x-ray films.

Neurological Evaluation

The neurological deficits of the patients were reappraised using the five-tier ASIA scores at the time of acute injury and at the censoring time. For the purpose of statistical analysis, the alphabetical ASIA scores were numerically assigned, with ASIA Score A being equal to 1, ASIA Score B being equal to 2, and so on. The functional statuses of the patients were evaluated using Nurick grades (Grade 1: normal walking with possible clinical spinal irritation; Grade 2: slight difficulties in walking with normal domestic and working life; Grade 3: functional disability limiting normal work and domestic activities; Grade 4: significant weakness making walking impossible without help; and Grade 5: bedridden or wheelchair bound). Patients were considered to have independent functional recovery if they achieved Nurick Grades 1 or 2.

Statistical Analysis

Nonparametric tests and the Fisher exact test were used to analyze the correlations between the variables of patient characteristics, types of SCIs seen on MR images, and the acute and final neurological outcomes in terms of ASIA scores. For all statistical tests, probability values less than 0.05 (two-tailed tests) were considered significant.

Results

Clinical Presentations and Treatments

Fifty-eight pediatric patients (infant–18 years old) in whom the diagnosis of spine injury or SCIs were made were treated and followed up at CGMH from January 1994 to July 2004. Nine preschool-aged children (15.5%) younger than 8 years old fulfilled the criteria for SCIWORA. The ages ranged from 2 months to 7.5 years old (mean 4.05 ± 2.79 years). The follow-up period ranged from 1 to 12 years (mean 5.14 ± 3.81 years). Table 1 shows the patients’ characteristics, status of the neurological deficits, functional recoveries, level(s) of SCI, and associated traumas. All patients in this study received external immobilization for at least 3 months, and no patient underwent spinal surgery. Seven patients received steroid treatment during acute posttraumatic hospitalization (megadose solumedrol therapy in three patients and dexamethasone infusion in four). Six patients (75%) had associated traumas in addition to the SCI. Three patients underwent laparotomies for associated blunt abdominal trauma, with one close thoracostomy for associated pneumothorax.

Neurological Outcomes and MR Images

All patients underwent MR imaging between 3 hours and 14 days after the traumatic incident. A 1.5-tesla magnet was used. On the T₂-weighted MR image, two patients displayed an extraneuronal soft-tissue abnormality: one displayed a hyperintense signal within the intervertebral discs and the other a folding of the yellow ligament adjacent to the cord contusion. No patient had an extramedullary compressing lesion, an epidural hematoma, or a ruptured disc. Four types of neuronal injury in the injured spinal cords were identified using MR imaging. Two patients had

<table>
<thead>
<tr>
<th>Case No.</th>
<th>Age (yrs), Sex</th>
<th>Cause of Injury</th>
<th>Level of Injury</th>
<th>Type of Cord Injury on MR Imaging</th>
<th>Associated Injuries</th>
<th>Time From Injury to Initial MR Imaging</th>
<th>ASIA Score</th>
<th>Nurick Grade</th>
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<tr>
<td>1</td>
<td>0.16, M</td>
<td>MVA C7-T1</td>
<td>SCT chest contusion</td>
<td>14 days 4.5 A A 5 5</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>2</td>
<td>2.5, M</td>
<td>MVA C7-T1</td>
<td>SCT liver laceration, pneumothorax</td>
<td>7 days 6.5 A A 5 5</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>3</td>
<td>3.3, F</td>
<td>MVA T-10</td>
<td>SCC small bowel perforation</td>
<td>6 hrs 1.0 A C 5 5</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>2.0, F</td>
<td>fall from 2 m</td>
<td>SCC none</td>
<td>7 days 2.0 B C 5 5</td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>7.5, M</td>
<td>MVA T2-3</td>
<td>SCC traumatic SAH, chest contusion, spinal laceration, femoral fracture</td>
<td>7 hrs 3.0 C C 5 5</td>
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<tr>
<td>6</td>
<td>6.8, M</td>
<td>fall T-10</td>
<td>SCE none</td>
<td>36 hrs 12 C D 5 2</td>
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<td>7</td>
<td>7.2, M</td>
<td>fall C4-5</td>
<td>norm mild head injury</td>
<td>4 hrs 4.5 D E 3 1</td>
<td></td>
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<tr>
<td>8</td>
<td>0.5, F</td>
<td>fall T5-6</td>
<td>norm none</td>
<td>6 days 6.3 D E 4 1</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>9</td>
<td>6.5, M</td>
<td>MVA C3-4</td>
<td>norm mild head injury</td>
<td>7 days 10.3 D E 3 1</td>
<td></td>
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* FU = follow up; MVA = motor vehicle accident; norm = normal appearance of spinal cord; SAH = subarachnoid hemorrhage; SCC = spinal cord contusion with major hematomyelia; SCE = spinal cord edema; SCT = spinal cord transection.
a transection of the spinal cord (Fig. 1), and both of them had permanent, complete sensorimotor dysfunction (ASIA Score A) below the injury level. Three patients had a cord contusion with hematomyelia located at the level of the injury (Fig. 2). One patient (Case 6) weighting 26 kg was witnessed to be paraplegic immediately after a ground-level slip and fall while running. The patient was conscious and afebrile after the accident. When he was brought to our emergency department, physical examination showed both normal blood pressure and cardiac rhythm. Neurological examination revealed nociceptive hypesthesia, areflexia, urine retention, and muscular weakness below the T-10 dermatome. Abdominal and spinal CT scans did not injury to the solid organs, great vessels, or thoracic vertebrae. A thoracolumbar MR image obtained 36 hours after the accident demonstrated an intramedullary, hyperintense T2-weighted signal in the conus medullaris without Gd–diethylenetriamine pentaacetic acid enhancement (Fig. 3). Because of the obvious history of the traumatic incident, the injury was thought to be a spinal cord contusion. Further investigation of cerebrospinal fluid was not done. The patient was treated with intravenous dexamethasone (5 mg every 6 hours) for 1 week and was discharged to rehabilitation in outpatient clinics with a neurological status of ASIA Score C and Nurick Grade 5. After rehabilitation for 10 years, he recovered his ambulatory function to a score of D but had a Nurick grade of 4. Because of spasticity and equina deformity of his feet, he needed a walker. He underwent Achilles tendon lengthening 10.5 years after the injury and could walk steadily without assistance 6 months after tendon lengthening; therefore, his final functional grade was coded as a Grade 2 and Score D. Meanwhile, a delayed thoracolumbar scoliosis with a Cobb angle of 18° developed after the 3rd year posttrauma; with bracing for 3 years it was corrected to 14° (Fig. 4A). The patient did not experience other neurological deficits representing new insults to the brain or cervical spinal cord in the following period. The follow-up MR images obtained 12 years posttrauma of the whole spine revealed a normal-appearing conus medullaris and no other spinal abnormality (Fig. 4B). The other three patients displayed either a normal appearance or an equivocal intramedullary, heterogeneous,
T2-weighted MR imaging signal of the spinal cord corresponding to their level of posttraumatic neurological deficit. These patients were considered to have cord concussion (Fig. 5). Although the different types of cord injuries did not correlate with the severities of the immediate posttraumatic neurological deficits represented by ASIA scores (Kruskal–Wallis test, \( p = 0.068 \)), they did correlate with the various neurological outcomes after 1 year of follow up \( (p = 0.046) \). Both patients with cord transection failed to recover from their complete cord injuries (Score A) after 4.5 and 6.5 years of follow up, respectively. The three patients who had major contusive spinal cord hemorrhages could only recover to ASIA Score C and had severe functional dysfunction below the injury levels. These five patients all had a functional Nurick grade of 5 at the censoring time.

The other three patients, who had no abnormal signal in the injured cord, recovered completely (ASIA Score E), and achieved complete functional independence (Nurick Grade 1) within 72 hours. These three patients were considered to have a spinal cord concussion. The patients with positive intramedullary lesions identified using MR imaging all failed to achieve independent functional recovery, and they had significantly worse Nurick grade than those without abnormal intramedullary signals on MR imaging \( (\text{Fisher exact test, } p = 0.048) \). In the present study, neither recurrent SCIWORA nor death occurred until the last follow-up investigation.

**Discussion**

Recognized in the pre–MR imaging era, SCIWORA was a diagnosis of SCI mainly based on radiography, such as plain x-ray films and CT scans. Usually vertebral fracture, degenerative osteophyte, or segmental subluxation would not be found in a spine harboring SCIWORA. Not until the introduction of MR imaging could pathological abnormalities in the injured spinal cord be clearly defined; on MR imaging, they manifest as an alteration of the intramedullary MR imaging signal, which can barely be identified on a CT scan. It is well accepted that MR imaging can display the specific relationship between the injury level of the spinal cord and the clinical neurological deficits. The procedure can also disclose associated para-

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**Fig. 3.** Magnetic resonance images. A: A T1-weighted image revealing an intramedullary hypointense signal. B: A T2-weighted image revealing an intramedullary hyperintense signal representing spinal cord edema. The lesion of the cord may be secondary to spontaneous spinal cord infarction, transverse myelitis, or vascular insult in a low-energy falling injury.

**Fig. 4.** Case 6. A: A follow-up thoracolumbar spine x-ray film 12 years after a falling injury. A thoracolumbar scoliosis with a Cobb angle of 14° is shown. B: A T2-weighted MR image of the whole spine at the 12-year follow up revealing a normal appearance of the conus medullaris and no other spinal abnormality.
spinal soft-tissue injuries as well as extramedullary compressing lesions such as a ruptured disc or an epidural hematoma. In SCIWORA, an MR imaging investigation may be the only option that can define the actual pathology of the spinal cord and indicate whether surgical intervention is necessary.

According to the existence and extension of an intramedullary hematoma and edema, Armstrong classified the T2-weighted MR imaging appearances of acute posttraumatic spinal cords into three types. The larger area of a low T2-weighted MR imaging signal within the cord represents the larger intramedullary hematoma and the poorer neurological recovery. Some MR imaging appearances of SCIWORA do not follow the Armstrong classifications of SCI. In early reports, a normal appearance or minimal swelling of the spinal cord was frequently seen on MR images, especially those depicting spines of children older than 8 years. In this group, the function of the long-track axons is temporarily disturbed by the transmission of externally applied kinetic energy, rather than by the direct compression or distraction of the spinal cord. This level constitutes the mildest form of SCIWORA, termed spinal cord concussion, in which the neurological deficits usually recover within 72 hours without neurological sequela. Matsumura, et al., reported the earliest single case report to correlate the abnormal MR imaging appearance of SCIWORA with neurological deficits: a 3-year-old patient with SCIWORA whose spinal cord had a hyperintense T2-weighted signal in the acute traumatic phase and who consequently suffered from permanent paraparesis. Grabb and Pang subdivided the MR imaging appearance of seven patients with SCIWORA into four categories: major hemorrhage, with hemorrhage in at least 50% of the transverse area of the cord; minor hemorrhage, with evidence of hemorrhage in less than 50% of the transverse area of the cord; edema only, with evidence of a hyperintense T2-weighted signal in the cord; and a normal cord appearance. Permanent and complete SCI will follow cord transection and major hemorrhage, but partial recovery of neurological function can be expected in the types involving minor hemorrhage or edema only. Complete recovery to Score E can be expected only in patients with a normal-appearing spinal cord on MR imaging. Also noted is the influence of age. In Grabb and Pang’s series, three patients younger than 8 years old suffered from transection or hemorrhagic injury of their spinal cord with severe permanent neurological deficits. Comparatively, only one of four patients older than 8 years of age had hemicordal edema and suffered from minor neurological deficits. With regard to analyzing the MR imaging data of patients younger than 8 years old separately, however, Grabb and Pang’s patient population was too small to address the significant correlation between abnormal MR images and poor neurological deficits. Bosch, et al., recently reported results of a large series of 60 MR imaging studies of SCIWORA with nine abnormal and 51 normal MR images. They found that abnormal MR imaging studies were three times more likely to occur in children younger than 8 years old compared with older children. As in previous reports, abnormal intramedullary MR images were also correlated with a failure of neurological recovery. To eliminate the bias of age, our study focused on children younger than 8 years of age, whose spines are much more flexible and resistant to mechanical stress than are their spinal cords. We did not observe the minor hemorrhagic cord injuries according to Grabb and Pang’s classification. The pattern of cord transection in the acute stage of SCIWORA represents the complete disruption of the neuronal anatomical continuity, and it certainly implies the
failure of neurological recovery. Although major hemorrhagic cord injuries involving more than 50% of the transverse area of the cord were prognostic of permanent complete deficits in previous reports, this prediction was not universally true in our three patients. Two of them (Cases 4 and 5) retained partial sensorimotor function with Scores B and C, respectively, after the initial trauma. Despite complete paraplegia immediately after injury, the patient in Case 3 recovered to Score C with a muscle power grade of 1 to 2 in the key muscles of the lower limbs 2 days later. All three children recovered to ASIA Score C only, however, remaining functionally disabled at the most recent follow up. Mottled increased T2-weighted MR imaging signals were identified in an inpatient (Case 6) who was injured in a low-energy fall when running. The edematous spinal cord could have resulted from vascular compromise during the injury, but the presence of transverse myelitis, multiple sclerosis, spontaneous spinal infarction, or an intramedullary tumor could produce a similar MR image. After 12 years of follow up, the patient regained functional ambulation without recurrent neurological deficits. The progressive improvement of neurological function without a recurring event and lack of initial enhancement of the lesion on MR imaging made the diagnosis of multiple sclerosis, transverse myelitis, or intramedullary tumor less likely. Because the patient’s abdominal CT scan did not disclose aortic injury or aneurysm, spontaneous spinal cord infarction (which shares a presentation and disease course similar to that seen in Case 6) should be considered as a possible cause of his sudden paraplegia. Our determination of spinal contusion was preferred, however, because of the obvious prior traumatic incident and the low probability of risk factors such as hypotension and artherosclerosis.

With elimination of the bias for age and anatomical influence, the MR imaging findings of SCIWORA in our study were prognostic of neurological outcomes, just as in the adult population. Magnetic resonance imaging may not be able to lead to better surgical or medical treatment to alter the outcomes of children with SCIWORA, but it does provide reliable prognostic information to predict the long-term outcome in the early posttraumatic stage. A normal MR image of the spinal cord in children with SCIWORA was prognostic of complete recovery in our study (p = 0.048). Predictably, the worst recovery, with a complete and permanent sensorimotor loss, was correlated with cord transection. Although variable recoveries occurred with the other transitional patterns of cord injury in which the anatomical continuity of the spinal cord was maintained, permanent neurological deficits and functional disability could be expected. We recommend that MR imaging be performed in any child who is thought to have suffered SCI, as soon as the patient becomes clinically stable.

Conclusions

Spinal cord injury without radiological abnormality is a distinct SCI of the pediatric population. Children younger than 8 years of age usually have more severe neurological deficits and outcome compared with older counterparts. Among patients with SCIWORA younger than 8 years of age, different cord injury patterns can be identified using MR imaging, such as transection, contusive hemorrhage, traumatic edema, and concussion. The MR imaging patterns of SCIWORA have significant prognostic correlations with the neurological outcomes of these patients. Spinal cord transection is prognostic of complete and permanent neurological dysfunction, and spinal cord concussion is prognostic of a complete neurological recovery. Patients with the other two patterns of cord injury have partial recoveries but remain functionally disabled. Magnetic resonance imaging provides a practical interpretation of the severity and a proper prediction of the prognosis of SCIWORA in these very young, preschool-aged children.

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