Radiology

Spinal Subdural Hemorrhage in Abusive Head Trauma: A Retrospective Study[1]

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Purpose: To compare the relative incidence, distribution, and radiologic characteristics of spinal subdural hemorrhage after abusive head trauma versus that after accidental trauma in children.

Materials and Methods: This study received prior approval from the Human Subjects Protection Office. Informed consent was waived. This study was HIPAA compliant. Two hundred fifty-two children aged 0–2 years treated for abusive head trauma at our institute between 1997 and 2009 were identified through retrospective chart review. A second group of 70 children aged 0–2 years treated at our institute for well-documented accidental trauma between 2003 and 2010 were also identified through retrospective chart review. All clinical data and cross-sectional imaging results, including computed tomographic and magnetic resonance imaging of the brain, spine, chest, abdomen, and pelvis, were reviewed for both of these groups. A Fisher exact test was performed to assess the statistical significance of the proportion of the spinal canal subdural hemorrhage in abusive head trauma versus that in accidental trauma.

Results: In the abusive head trauma cohort, 67 (26.5%) of 252 children had evaluable spinal imaging results. Of these, 38 (56%) of 67 children had undergone thoracolumbar imaging, and 24 (63%) of 38 had thoracolumbar subdural hemorrhage. Spinal imaging was performed in this cohort 0.3–141 hours after injury (mean, 23 hours ± 27 [standard deviation]), with 65 (97%) of 67 cases having undergone imaging within 52 hours of injury. In the second cohort with accidental injury, only one (1%) of 70 children had spinal subdural hemorrhage at presentation; this patient had displaced occipital fracture. The comparison of incidences of spinal subdural hemorrhage in abusive head trauma versus those in accidental trauma was statistically significant ($P < .001$).

Conclusion: Spinal canal subdural hemorrhage was present in more than 60% of children with abusive head trauma who underwent thoracolumbar imaging in this series but was rare in those with accidental trauma.

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Abusive head trauma is the leading cause of substantial traumatic brain injury in infants, with 20%–38% mortality and substantial neurologic and developmental impairment in 30%–78% of survivors (1–4). The radiologic features of abusive head trauma have been well characterized in a number of studies (1–3,5) and include intracranial hemorrhage, most commonly subdural in location, and brain injury, typically manifested as parenchymal hypoattenuation or loss of gray-white differentiation at computed tomography (CT). Evidence of impact injury such as skull fractures are present in 15%–27% of cases (1,6). Retinal hemorrhages are present at ophthalmoscopy in approximately 80%–92% of cases (1,7) and may also be visible at magnetic resonance (MR) imaging (8).

Spinal injuries are an additional well-documented feature of abusive head trauma, although a less common feature than intracranial injuries, and may include direct spinal cord injuries, nerve root injuries or avulsions, epidural and subdural hemorrhages, and spinal ligamentous injuries or bone edema or fractures (7,9). A recent autopsy study by Brennan et al (7) documented evidence of spinal column, spinal cord, and/or cervical nerve root injuries in 71% of fatal cases. Spinal injuries may be overlooked clinically in nonfatal cases because of coexistent brain injury and traumatic coma; in one review (9), associated spinal injuries were not recognized initially in more than half of cases.

In this current retrospective study, we reviewed our experience with spinal subdural hemorrhage in a cohort of children aged 0–2 years with abusive head trauma and contrasted our findings in this group with findings in a cohort of similarly aged children with accidental trauma. The purpose of this study was to compare the relative incidence, distribution, and radiologic characteristics of spinal subdural hemorrhage after abusive head trauma versus after accidental trauma in children, with an aim of better understanding the origin.

Advances in Knowledge

- Spinal canal subdural hemorrhage was present in more than 60% of children with abusive head trauma in whom thoracolumbar imaging was performed.
- Spinal canal subdural hemorrhage was rare in accidental trauma.

Materials and Methods

This study received prior approval from the Human Subjects Protection Office. Informed consent was waived. This study was Health Insurance Portability and Accountability Act compliant. A retrospective study was performed comparing the prevalence of spinal subdural hemorrhage in abusive head trauma versus that in accidental injury in young children. All children aged 0–2 years treated for abusive head trauma at our institute between 1997 and 2009 were identified through retrospective chart review. Our institute maintains a child abuse registry, and the abusive head trauma cases were manually identified from that registry. All clinical data were abstracted to determine the time of the injury (or reporting of injury) whenever possible, demographics, clinical presentation, radiologic findings, and clinical outcomes. The clinical charts were reviewed by a 3rd-year medical student (R.K.B.) and pediatric neurosurgeon (M.S.D., with more than 15 years of experience). Results of all cross-sectional imaging (including CT and MR imaging) of the brain and spine (cervical, thoracic, and lumbar spine) and CT of the chest, abdomen, and/or pelvis were evaluated, including images obtained at admission as well as those obtained subsequently. If there were no clinical data or CT or MR imaging of the brain and spine, patients were excluded. The imaging of abusive head trauma has evolved over the course of time (1997–2009) at our institute. Imaging of the brain and cervical spine was routine for abusive head trauma, reflected by the fact that the majority of our cases included imaging of the brain and cervical spine. Abdominal CT has been performed more routinely in recent times with clinical suspicion of abdominal injury and increased awareness of abdominal injury in abusive head injury. In some cases, follow-up MR imaging was performed in the thoracolumbar spine after suspicion was raised for spinal subdural hemorrhage at either abdominal CT or cervical spine imaging. Follow-up MR imaging occasionally was performed for clinical suspicion of injury such as back pain or priapism. We identified 252 children with abusive head trauma during the study period; 113 of 252 had complete clinical and cranial radiologic data to analyze. Forty-six of 113 of these children lacked spinal imaging results and were excluded. The remaining 67 of 113 children had undergone cross-sectional imaging (CT and/or MR imaging) of at least one spinal region (Fig 1, Table 1).

A second group of children aged 0–2 years treated at our institute for well-documented accidental trauma between 2003 and 2010 were also identified through retrospective chart review. The selection criteria included clinical concern for a head injury and abdominal or spinal injury. This was chosen to compare the presence of spinal subdural hemorrhage between the two cohorts.

Implications for Patient Care

- Our study will increase awareness and subsequently improve detection of spinal subdural hemorrhage in abusive head trauma.
- Nonaccidental trauma should be carefully considered in patients with spinal subdural hematoma.

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Guarantor of integrity of entire study, A.K.C.; study concepts/study design or data acquisition or data analysis/interpretation, all authors; manuscript drafting or manuscript revision for important intellectual content, all authors; manuscript final version approval, all authors; literature research, all authors; clinical studies, A.K.C., M.S.D., G.J.M., D.K.B.B.; statistical analysis, A.K.C., R.K.B.; and manuscript editing, all authors

Potential conflicts of interest are listed at the end of this article.

Figure 1

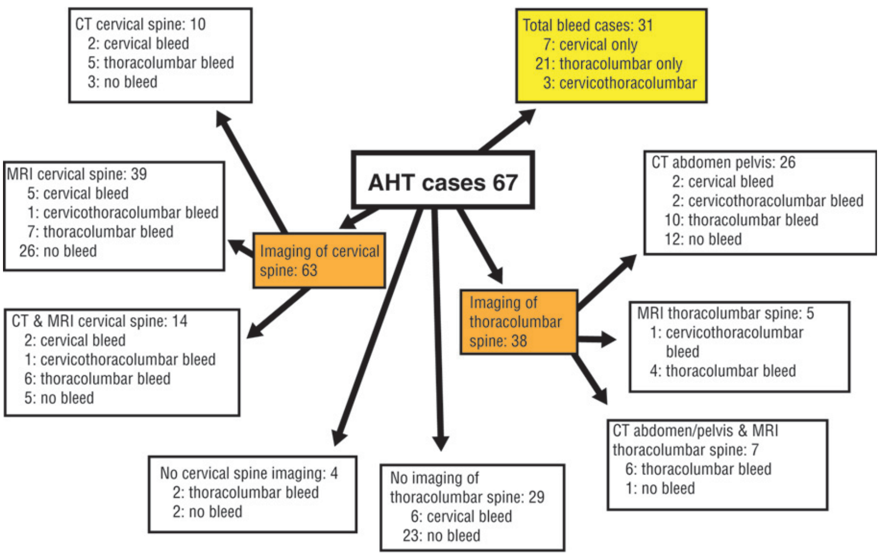


Figure 1: Chart of the imaging studies performed in the 67 cases of abusive head trauma *(AHT).*

Table 1

Analysis of 0–2-Year-Old Children at Our Institution

Parameter	Abusive Head Trauma	Accidental Trauma
Time period	1997–2009	2003–2010
Total no. of patients analyzed	252	70
Complete clinical and cranial data available	113	70
Imaging results in spine available	67	70
Positive result for intracranial subdural bleed	62 (93)	22 (31)
Positive result for thoracolumbar spinal subdural bleed only	24/38 (63)	1/70
Positive result for cervical spinal subdural bleed only	7/29 (24)	0
Negative result for intracranial bleed	5 (7)	48 (69)
Overall spinal subdural bleed	31/67 (46)	1/70 (1)

Note.—Data are numbers of cases, with percentages in parentheses.

All available cross-sectional imaging results, including CT and MR images of the brain, spine, chest, abdomen, and pelvis, were similarly reviewed. Subjects were excluded if there was abusive head injury or if any cross-sectional imaging of the spine was not available.

All images were independently analyzed by two experienced neuroradiologists (A.K.C., with 6 years of experience; G.J.M., with more than 10 years of experience in brain research). The images of the accidental and abusive head trauma cohorts were reviewed randomly, with the readers blinded to clinical history and diagnosis. After independent analysis, interobserver differences were resolved by using consensus. Radiologic evidence of traumatic spinal injury was sought in all cases and included evidence of hemorrhage in the epidural or subdural space, which resulted in nodular or smooth dural thickening, presence of mass effect on the cord, and/or effacement of the subarachnoid space (Figs 2, 3). We considered bleed to be subdural in location if the epidural fat was normal in signal intensity and there was no displacement of dura and epidural in location if there was displacement of the dura with nonvisualization of the epidural fat or stranding of the dural fat (10). The hemorrhage was less T1 hyperintense than fat and therefore easily distinguishable on MR images. We also correlated with T2-weighted and short inversion time inversion-recovery images to ensure no false-positive findings from fat in the spinal canal. Similarly, the hemorrhage was hyperattenuating at CT compared with adjacent structures and was easily distinguishable. Whenever possible, the reporting time of the injury was established through review of the medical records, and the time from the injury to each of the imaging studies was calculated. If both cranial and spinal subdural hemorrhages were present, the hemorrhage attenuation on CT images and/or signal intensity on MR images in both locations were compared to see if they were different or similar.

Statistical Analysis

We performed a Fisher exact test by using software (SAS, version 9.2, 2010; SAS Institute, Cary, NC) to assess for any statistical significance between the incidences of spinal subdural hemorrhage in abusive head trauma versus those in accidental trauma. A *P* value of less than .05 was considered indicative of a statistically significant difference. κ Statistics were calculated for interobserver agreement by using software (SPSS, version 18, 2010; SPSS, Chicago, Ill). κ Values of 0–0.20, 0.21–0.040, 0.41–0.60, 0.61–0.80, 0.81–0.99, and 1.00 were considered to represent slight, fair, moderate, substantial, excellent, and absolute agreement, respectively.

Results

Abusive Head Trauma Cohort

Of the 252 children with abusive head trauma during the study period, 139 cases were excluded for lack of complete clinical data and 46 were excluded for lack of complete radiologic data. We identified 67 children between 0 and 2 years with abusive head trauma who had undergone both head and abdominal or spinal imaging. Among the 67 cases, there were 44 (66%) male patients and 23 (34%) female patients with a mean age of 6 months. Spinal imaging was

Figure 2

a.

b.

c.

Figure 2: Images in 7-month-old male patient. **(a)** Axial abdominal CT image and **(b)** sagittal reconstruction show hyperattenuating nodular thickening of the posterior dura. **(c)** Sagittal T1-weighted MR image shows hyperintense subdural hemorrhage (arrow). Note that the maximum thickness of spinal subdural hemorrhage is in the region of thoracolumbar junction, which is the most dependent region in the infant lying down. This causes slight effacement of subarachnoid space but no compression of the cord or nerve roots. The epidural space appears normal with no evidence of bone or ligamentous injury.

performed between 0.3 and 141 hours after reporting of injury, with a mean of 23 hours ± 27 (standard deviation), and 97% of cases underwent imaging within 52 hours of injury. One of 67 had bone injury to the posterior elements of the lumbar spine with paraspinal hematoma and small epidural hemorrhage. One of 67 had signal abnormality of the cord, which could have represented contusion or infarct. This patient also had spinal canal subdural hemorrhage.

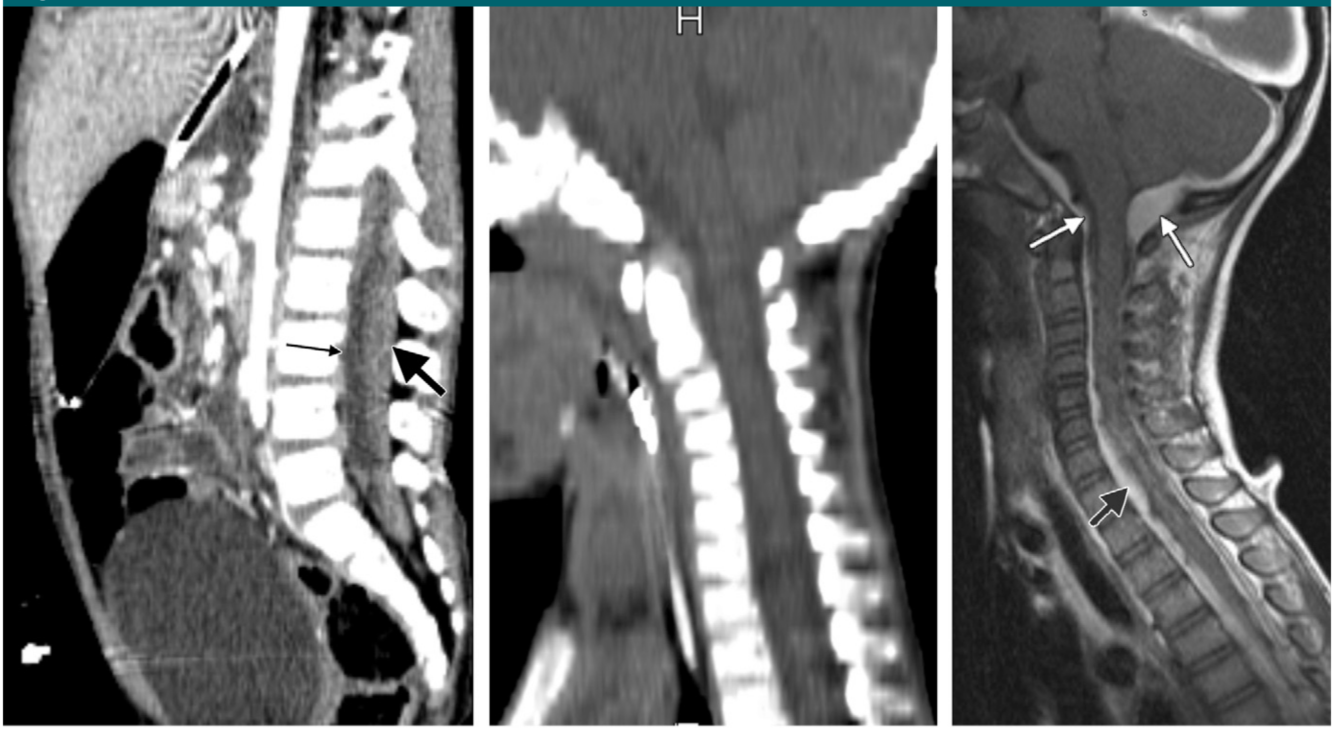
Of the 67 children with evaluable spinal imaging results, 31 (46%) had spinal subdural hemorrhage. Of the 29 children with only cervical spine imaging results, seven (24%) cases had cervical subdural hemorrhage. Because none of these children had undergone thoracolumbar imaging, cases with thoracolumbar subdural hemorrhage could have been missed, and the incidence of spinal subdural hemorrhage therefore underrepresented among this group. Of the 38 children with thoracolumbar imaging results, 24 (63%) had thoracolumbar subdural hemorrhage (Table 1, Fig 1). Among those cases with spinal subdural hemorrhage, all had intracranial supratentorial and posterior fossa subdural hemorrhage, including 15 with small intracranial subdural hemorrhage and 16 with moderate intracranial subdural hemorrhage. Some of the cases did not have cervical bleed but had presence of bleed in the thoracolumbar region. Among the 14 children without thoracolumbar subdural hemorrhage, two had no intracranial subdural hemorrhage, 11 had small intracranial subdural hemorrhage, and one had moderate intracranial subdural hemorrhage. Only two patients were symptomatic from their spinal injuries, one with persistent priapism and the other with back pain.

Among all children with both spinal and intracranial subdural hemorrhage, the subdural hemorrhages in both locations had similar attenuation and/or signal intensity. The majority of the subdural hemorrhage was identified along the posterior dura; however, there were cases where spinal subdural bleed was circumferential and also cases where it was exclusively anterior.

Accidentally Injured Cohort

We identified 70 children between 0 and 2 years with accidental trauma with clinical concern for head and abdominal or spinal injury and who had undergone both head and abdominal or spinal imaging. There were 48 (69%) male patients and 22 (31%) female patients with a mean age of 1 year. Of these, 47 patients had undergone imaging of the cervical spine as well. Forty-eight (69%) of 70 patients had neither intracranial nor spinal subdural hemorrhage. The remaining 22 (31%) children had intracranial subdural hemorrhage (Table 1), 14 with small subdural hemorrhage, six with medium subdural hemorrhage, and two with large subdural hemorrhage. A single patient had spinal subdural hemorrhage at presentation; this patient had substantial posterior fossa

Figure 3



b.   c.   d.

a.

Figure 3: Images in 2-year-old female patient. **(a)** Axial abdominal CT image and **(b)** sagittal reconstruction show hyperattenuating subdural hemorrhage along the posterior dura (thick arrow). There is associated mass effect with effacement of the subarachnoid space and displacement of the cord anteriorly (thin arrow). The epidural space appears normal with no evidence of bone or ligamentous injury. **(c)** CT neck sagittal reconstruction in the same patient shows no spinal subdural hemorrhage. **(d)** Sagittal T1-weighted MR image obtained 10 days later in the patient (while she was still in the hospital to rule out ligamentous injury) shows hyperintense (black arrow) subdural hemorrhage in continuity with the posterior fossa both anteriorly and posteriorly (white arrows). Posterior fossa and spinal canal hematoma are of similar signal intensity.

injuries, including a displaced comminuted occipital bone fracture and cerebellar contusions.

Statistical Analysis

In the abusive head trauma group, there was an overall incidence of 31 (46%) of 67 cases of spinal subdural bleed with an even higher percentage in cases where the thoracolumbar spine was also imaged (24 [63%] of 38). In contrast, in the cohort with accidental trauma, there was an incidence of one (1%) of 70 with spinal subdural bleed ($P < .001$). Interobserver agreement for assessment of presence or absence of spinal canal subdural hemorrhage was excellent in the abusive head trauma cohort, with a κ value of 0.91 (Table 2). There was absolute agreement in the assessment of spinal canal subdural hemorrhage in the accidental trauma cohort, with a κ value of 1.00.

Discussion

Spinal injury in the context of abusive head trauma has been an infrequently documented finding and may be missed clinically. The lack of reported spinal injuries in nonfatal cases may reflect infrequent imaging of the thoracolumbar spine (which was where we found the majority of our spinal subdural hemorrhages), technical challenges such as motion, streak artifacts on CT images, small isointense or isoattenuating hemorrhage, as well as clinical difficulty in recognizing coexistent spinal injuries in gravely ill infants with severe traumatic brain and other injuries. We found in our study a high incidence of spinal subdural hemorrhage in abusive head trauma in cases where the thoracolumbar spine was imaged. This is an important finding that may help to distinguish between abusive and accidental injury and to understand the mechanism of injury with further studies.

Spinal injuries appear to be a relatively frequent concomitant of fatal abusive head trauma. In a recent autopsy series by Brennan and colleagues (7), 29 (71%) of 41 demonstrated evidence of spine or spinal cord injury, 24 (83%) of whom had evidence of meningeal

Table 2

Interobserver Correlation

Group	Reader 1		Reader 2		κ Value
	Presence of Spinal Subdural Hemorrhage	Absence of Spinal Subdural Hemorrhage	Presence of Spinal Subdural Hemorrhage	Absence of Spinal Subdural Hemorrhage	
Abusive head trauma	31	36	30	37	0.91
Accidental trauma	1	69	1	69	1.00

Note.—Unless otherwise indicated, data are number of cases.

bleeding. There have been scattered case reports of spinal subdural hemorrhage in abusive head trauma (11,12), although systematic studies have been lacking. A recent study (11) utilizing spine MR imaging identified spinal subdural hemorrhage in 44% of cases. In the present series, the higher incidence of 63% for positive result for spinal subdural bleed, where thoracolumbar region was imaged, may reflect the review of results of all cross-sectional imaging (including CT of the chest, abdomen, and pelvis, as well as spinal MR imaging). Review of prior published reports in which spinal canal subdural hemorrhage was seen in conjunction with intracranial hemorrhage includes accidental or abusive trauma, surgery, aplastic anemia, and metastatic melanosarcoma (10–31). In these reports, the earliest detection of spinal subdural hemorrhage was 3 days after injury, with a mean of 13.4 days after injury to detection of spinal canal subdural hemorrhage. Although injuries to the spinal cord and/or spinal column provide evidence of direct spinal trauma, the origin of spinal subdural hemorrhages in abusive head trauma is less certain. The two proposed mechanisms regarding the origin of spinal subdural hemorrhage reported in the literature include *(a)* tracking of intracranial subdural hemorrhage into the spinal compartment by gravity or some other unknown mechanism (11,19,24–27,31) or *(b)* a direct injury to vessels in or around the spinal cord but within the dural compartment. In favor of the first theory, multiple clinical reports document the association between intracranial subdural hemorrhage and spinal subdural hemorrhage, both after cranial trauma (including abusive head trauma) without overt spine trauma, as well as after cranial operations (10–31). In particular, tracking of subdural hemorrhage into the spinal canal after neurosurgical procedures has also been reported (24–27,29). With regard to anatomy, there is a relative lack of vessels within the subdural space of the spinal canal (32), unlike the bridging veins of the cranial compartment. The other proposed hypotheses include sudden increases in intraabdominal pressure resulting in rupture of a spinal hemorrhage vessel with spinal subdural hemorrhage (33,34), hyperflexion of the spine causing injury to the vessels traveling within the spinal nerve sheath along the spinal nerves as well as the ventral and dorsal nerve roots that result in bleeding into the subdural space (12), and increased intracranial pressure indirectly increasing the shearing force between spinal subdural and subarachnoid spaces that results in tear and bleeding of the inner dural layer of the spine (17,35). Some of these hypotheses are not well accepted facts and lack any evidence.

Spinal subdural hemorrhage has been managed both surgically (12,19,36,37) and nonsurgically (11,17,20,38,39). Surgical intervention is generally reserved for those cases with clinical or radiologic evidence of spinal cord compression. All of the children in the present series were treated nonsurgically, including both symptomatic cases with some spinal cord compression at imaging. There is no described case report of priapism caused by spinal cord compression by hematoma in the abusive head trauma literature. None of the children had any long-term complications from spinal cord compression at follow-up, including the two symptomatic children. Management should therefore be individualized.

There were a number of limitations of this retrospective study. Ascertaining a definite timing of injury is difficult in abusive head trauma because of the nature of the trauma, and this was a weakness of this study. However, in our experience with our abusive head trauma cases, there was usually an event that brought the patient to the hospital with severe injuries requiring immediate clinical support. Catastrophic and ictal clinical changes including apnea that may be seen in these cases are also probably reliable indicators of the time of injury (1). The second weakness of this study related to the fact that this was a retrospective study in which some of the patients underwent thoracic, abdominal, or pelvic CT and some patients underwent spinal MR imaging. This was also a reflection of change in the clinical approach during the time of the study. In general, we assume that chest, abdominal, pelvic, or spinal imaging was performed if there was a concern for injury. That is why we chose to have a similar control group of accidental injury where there was concern for both abdominal or spinal and intracranial injury. If the cause of spinal subdural hemorrhage were abdominal injury, we should see a similar incidence of spinal subdural hemorrhage in both of the groups. The third weakness related to the management of the spinal subdural hemorrhage. There are reports recommending surgical management (11,18,36,37); however, all of our cases were managed conservatively. On the basis of our small sample size, we cannot recommend a management approach for these cases. Therefore, we recommend individualized management, and this issue probably needs to be studied further.

To further study the disease process, we should be imaging the entire spine in cases suspicious for abusive head trauma. We may also potentially study cases with intracranial subdural hemorrhage with sequential imaging such as ultrasonography or MR imaging to assess the pattern of migration of intracranial subdural hemorrhage and whether it tracks down to the spinal canal. If it does migrate, the factors controlling the migration and the timeline of migration will be important to understand the process.

Spinal canal subdural hemorrhage was present in more than 60% of children with abusive head trauma who underwent thoracolumbar spine imaging in this series. Although usually clinically asymptomatic, subdural hemorrhages could lead to complications from spinal cord compression. As others have (7,9), we urge considering complete spine imaging for all children undergoing brain MR imaging for moderate or severe traumatic brain injury, both accidental and abusive.

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