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# MR Imaging of the Cervical Spine in Nonaccidental Trauma: A Tertiary Institution Experience

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## ABSTRACT

**BACKGROUND AND PURPOSE:** Cervical MR imaging has demonstrated a utility for detecting soft tissue injury in nonaccidental trauma. The purpose of this study was to identify the incidence and types of cervical spine injury on MR imaging in nonaccidental trauma and to correlate cervical spine injury with parenchymal injury on brain MR imaging and findings on head CT.

**MATERIALS AND METHODS:** A retrospective review of children diagnosed with nonaccidental trauma in a tertiary referral pediatric hospital over 8 years was performed. Inclusion criteria were children younger than 5 years of age, a confirmed diagnosis of nonaccidental trauma, and cervical spine MR imaging within 1 week of presentation. Brain and cervical spine MR imaging, head CT, cervical radiographs, and skeletal surveys were reviewed.

**RESULTS:** There were 89 patients included in this study (48 males; mean age, 9.1 months [range, 1–59 months]). Cervical spine injury on MR imaging was found in 61 patients (69%). Ligamentous injury was seen in 60 patients (67%), with interspinous ligaments being most commonly involved. Abnormal capsular fluid (atlanto-occipital and atlantoaxial) was present in 28 patients (32%). Cervical spine injury on MR imaging was significantly associated with parenchymal restricted diffusion on brain MR imaging and parenchymal injury on head CT ( $P = .0004$  and  $P = .0104$ , respectively). Children with restricted diffusion on brain MR imaging were 6.22 (point estimate) times more likely to have cervical spine injury on MR imaging.

**CONCLUSIONS:** There is a high incidence of cervical spine injury in pediatric nonaccidental trauma. Positive findings may affect management and suggest a traumatic etiology.

**ABBREVIATIONS:** AHT = abusive head trauma; CSI = cervical spine injury; NAT = nonaccidental trauma

Cervical spine injury (CSI) is uncommon in children, accounting for only 1–2% of pediatric trauma.<sup>1</sup> There is a higher prevalence of upper cervical injury in infants and toddlers, secondary to mechanism of injury and physiologic immaturity. Younger children are also more likely to have a ligamentous injury than fractures.<sup>2</sup> A high clinical suspicion and the appropriate use of imaging are the key factors in identifying CSI. Ligamentous injury to the cervical spine is a well-recognized but likely underdocumented condition in pediatric cervical spine trauma, especially when accompanied by complex coexistent injuries or a delay in clinical symptoms.<sup>3</sup>

Recent literature suggests ligamentous injury documented on cervical MR imaging is commonly found in children with abusive head trauma (AHT).<sup>4,5</sup> Spinal injuries in AHT described in various studies include compression fractures, ligamentous injury, cord injury, and subdural hematoma.<sup>6–9</sup> The ligamentous injury is believed to be secondary to a hyperflexion/hyperextension mechanism of injury, and the younger the child, the more likely the upper cervical spine is at risk for injury. The infant or young child's physical features increase the risk of ligamentous CSI because of the presence of a relatively large head size, ligamentous laxity, and poorly developed paraspinal musculature.<sup>1,2</sup> The incidence of CSI is likely underestimated because cervical MR imaging is not generally part of the routine evaluation of nonaccidental trauma (NAT) with or without evidence of AHT. This is frequently secondary to the absence of abnormalities on radiographs that are part of the routine NAT evaluation. The lack of clinical suspicion of CSI, along with coexistent head injuries, increases the risk of masking the clinical detection of CSI.

The purpose of our study was to identify the incidence and

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types of CSI on MR imaging in a cohort of pediatric patients diagnosed with NAT with or without AHT and to correlate CSI with parenchymal injury on brain MR imaging and findings on head CT.

## **MATERIALS AND METHODS**

### **Patients**

This was a Health Insurance Portability and Accountability Act-compliant descriptive retrospective study performed after approval from the institutional review board at a pediatric tertiary referral center. Using the center's trauma registry, a query was generated to provide a study data base including all children younger than 5 years of age who presented with NAT from July 2004 through September 2012. The trauma registry is a disease-specific data collection composed of a file of uniform data elements designed to capture data. From the generated query results, charts were evaluated thoroughly to determine study eligibility. Children with spinal injuries resulting from mechanisms other than NAT were not included. Only the patients in whom NAT had been documented by the child abuse team were included in the study data base. The presence of AHT was not a requirement for inclusion, but the diagnosis of NAT was. The discharge status was evaluated to identify mortality related to NAT in this cohort.

The inclusion criteria were children younger than 5 years of age presenting during the study period with a diagnosis of NAT and sagittal STIR cervical spine MR imaging performed within 1 week of presentation. Patients with nondiagnostic sagittal STIR images were excluded. Children with NAT admitted to the inpatient service or intensive care unit typically had cervical MR imaging performed along with brain MR imaging. All records from the study data base labeled as NAT were reevaluated by the medical providers with training and experience in child abuse pediatrics. All patients were evaluated based on the criteria adapted from Feldman et al<sup>10</sup> in 2001 for classifying children with head trauma as either abusive or accidental. Based on this classification schema, which takes into account other injuries, the developmental level of the child, the history of trauma provided, and whether a witness was present, cases found to be highly likely abusive and definitely abusive were included in our final study data base. Highly likely abusive was defined as injuries of different ages and not appropriate for given history, absent history, or developmentally unlikely history. Definitely abusive was defined as a corroborated, witnessed, or confessed event. Definitely abusive was also defined as multiple injuries that are incompatible with normal, unintentional childhood injury. Children classified as likely abused or indeterminate were not included because the diagnosis was less than certain.

MR imaging of the cervical spine and brain was reviewed by consensus of 2 experienced pediatric neuroradiologists with 13 and 17 years of experience. Cervical radiographs, skeletal surveys, and available brain imaging were also reviewed.

### **Imaging Analysis**

Cervical spine MR imaging was performed at 1.5T or 3T. Imaging sequences obtained for a routine trauma cervical spine MR imaging include sagittal STIR images, sagittal T1WIs, axial T2WIs, and axial T2 gradient-echo images. Image quality was assessed with

attention to SNR, extent of fat suppression on STIR images, and motion artifacts. The studies were subjectively categorized as nondiagnostic, diagnostic, and superior; nondiagnostic studies were excluded from evaluation.

MR imaging evaluation of the cervical spine included the presence or absence of cord edema or hemorrhage, ligamentous injury, joint capsule fluid (atlanto-occipital and atlanto-axial) with or without distension, marrow edema, and subdural and epidural hemorrhage or fluid. Craniocervical ligamentous structures evaluated included tectorial and atlanto-occipital (anterior and posterior) membranes. Lower cervical ligamentous structures included anterior and posterior longitudinal ligament and ligamentum flavum. Interspinous ligaments were deemed abnormal when abnormal increased T2 signal was present in the interspinous location and classified as cervical or upper thoracic. Injury to the nuchal ligament was identified when fluid signal intensity was seen both anterior and posterior to the structure. CSI by MR imaging was defined when one of the following was present: bone marrow edema, ligamentous injury, joint capsular fluid, regional soft tissue edema including epidural fluid, or spinal cord edema/hemorrhage. Subdural hemorrhage was not included because this most likely resulted from redistribution of intracranial subdural hemorrhage.

Cervical spine radiographs were classified as diagnostic or nondiagnostic. The quality of the study was evaluated based on proper positioning of the patient, visibility of 7 cervical vertebrae, and image quality. Cervical spine radiographs were evaluated for alignment, prevertebral swelling, and fractures.

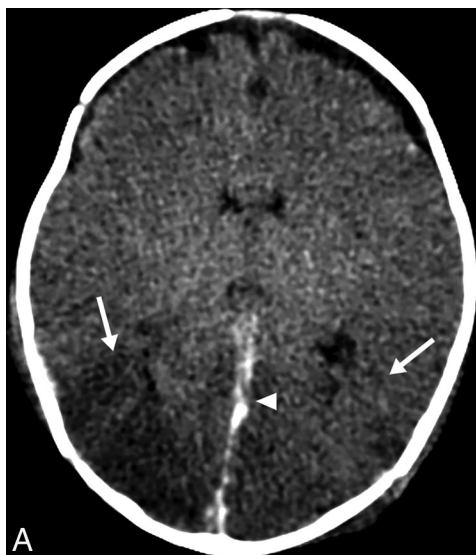
The brain MR imaging was evaluated for the presence of parenchymal restricted diffusion. The restricted diffusion was classified as focal, multifocal, or diffuse. A focal injury was defined as an injury in 1 or 2 lobes. A multifocal injury was defined as an injury in more than 2 lobes. A diffuse pattern injury was defined as diffuse bilateral distribution, suggesting a hypoxic-ischemic insult. There were 4 patients who had a cervical MR imaging, but no brain MR imaging.

Baseline head CT was available for all patients and assessed for presence of parenchymal injury, SAH, subdural hemorrhage or fluid, and fractures. If present, subdural hemorrhage was evaluated and classified based on its attenuation into hypoattenuated (hygroma), mixed (hypo- and hyperattenuated components), and hyperattenuated subdural hemorrhage. When available, follow-up head CT was evaluated for presence of redistribution of subdural hemorrhage. Redistribution was defined as an increase in the dependent located subdural hemorrhage with a corresponding decrease in the volume of subdural hemorrhage located anterior and superior.

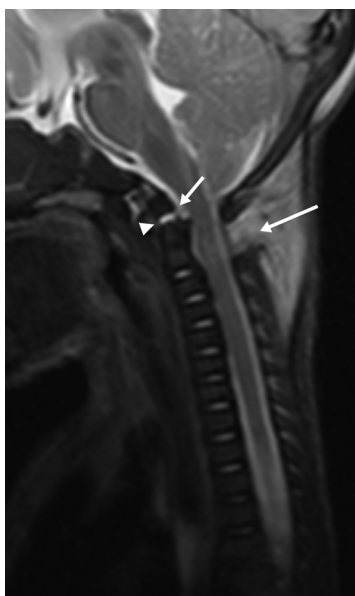
Skeletal surveys were evaluated for the presence of fractures, which were classified as acute, healing, and mixed age.

### **Statistical Analysis**

Univariate tests (Wilcoxon rank-sum test and Fisher exact test) were performed to characterize the age of the patient on measured parameters including the presence of spinal injury diagnosed by MR imaging, bone marrow edema, ligamentous injury, restricted diffusion in brain, and subdural hematoma on head CT. In addition,



**FIG 1.** Three-month-old patient. A, Axial CT demonstrates interhemispheric subdural hemorrhage (arrowhead) and symmetric edema of the bilateral occipital lobes (arrows). There is abnormal low attenuation in the basal ganglia. Superior frontal parietal edema is present as well (not shown). B, Sagittal midline STIR image shows interspinous ligamentous injury at all cervical levels (arrows), paraspinal muscular injury, nuchal ligament injury (arrowhead), and marrow edema involving the lower cervical and upper thoracic vertebral bodies, most prominent at T1 (long arrow).



**FIG 2.** Five-month-old patient. Sagittal midline STIR image shows a dens fracture (arrowhead) and disruption of the inferior tectorial ligament anterior longitudinal ligament junction (short arrow). Extensive injury to the C1-2 interspinous ligamentous structures (long arrow) and edema in the posterior paraspinal musculature are present. Diffuse parenchymal injury was present on CT and MR imaging (not shown).

tion, CSI diagnosed by MR imaging was correlated with age, parenchymal injury on CT and MR imaging, subdural collections, and skull fracture. A stepwise logistic regression model was performed, accounting for the significant univariate parameters. All analyses were performed with the SAS 9.3 system (SAS Institute, Cary, North Carolina). All  $P$  values  $< .05$  were considered statistically significant.

## RESULTS

### Clinical

The retrospective review of medical records of children with MR imaging of the cervical spine performed within 1 week of admission identified 94 patients, of which 5 were excluded either because of absence of a sagittal STIR sequence ( $n = 3$ ) or nondiagnostic quality of the study ( $n = 2$ ). The established criteria were met by 89 patients (48 males). The median and mean ages were 5 and 9.1 months, respectively (range, 1–59 months). There was 5% mortality during the hospital stay ( $n = 5$ ). Abusive head trauma was present in 92% ( $n = 82$ ) of patients. In the remainder of cases ( $n = 7$ ), the diagnosis of NAT was made based on evidence of other non-neurologic injuries.

### Imaging Findings

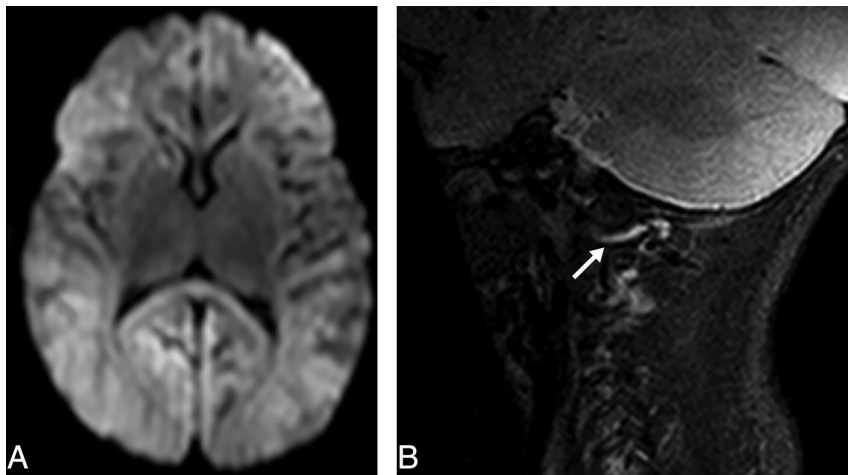
In this study, 85 children (96%) with NAT admitted to the inpatient service or intensive care unit had cervical MR

imaging performed; brain MR imaging was used to further evaluate NAT. Of the 4 patients without a brain MR imaging, head CT was normal in 1 and showed subdural hemorrhage in 3. All patients were imaged with a head CT, which was interpreted as normal in 9% of patients ( $n = 8$ ). Of these patients with a normal CT, brain MR imaging was obtained in 7; 6 patients demonstrated normal brain MR findings and restricted diffusion was seen in 1 patient.

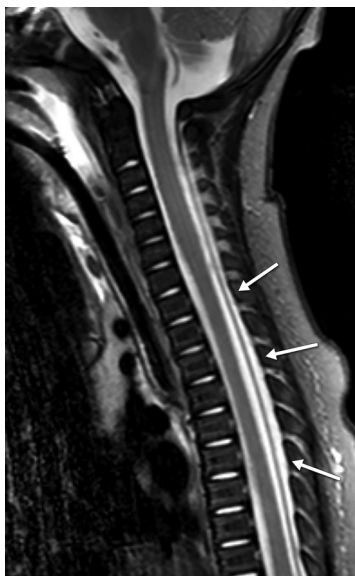
Cervical MR imaging was performed on a 1.5T magnet in 82% of the cases. The quality of the MR imaging was superior in 43% and diagnostic in 57% of the cases. CSI diagnosed by MR imaging was present in 69% ( $n = 61$ ). The mean age of children with CSI by imaging was 9.4 months, and the mean age of children without CSI by imaging was 8.54 months ( $P = .46$ ). Bone marrow edema was more commonly seen in older children (mean age, 14.9 months;  $P = .028$ ), and capsular injury was seen in younger children (mean age, 5.5 months;  $P = .0064$ ). Of the patients who displayed CSI by MR imaging, 64% had diagnostic-quality cervical radiographs. Only 10% of patients in this group had abnormal findings on the cervical radiograph, most commonly nonspecific prevertebral soft tissue prominence greater than one-half of adjacent vertebral body at C2–3. Only 2 patients had an abnormal basion-dens interval measuring greater than 12 mm. No cervical fractures were present.

Ligamentous injury was seen in 67% of patients ( $n = 60$ ). The most common types of ligamentous injury were cervical interspinous ligaments (65%), upper thoracic interspinous ligaments (46%), and nuchal ligament (39%) (Fig 1). There were 3 patients with tectorial membrane injury (Fig 2), 2 with ligamentum flavum injury, and 1 with posterior atlanto-occipital membrane injury. There were no cases of transverse ligament, anterior longitudinal ligament, or posterior longitudinal liga-





**FIG 3.** Two-month-old patient. A, Axial trace DWI shows diffuse restricted diffusion involving the bilateral cerebral hemispheres. B, Sagittal paramidline STIR image shows abnormal fluid within the atlanto-occipital joint space with mild distension (arrow), consistent with capsular injury.



**FIG 4.** Four-month-old patient. Sagittal midline T2WI shows abnormal posterior extradural fluid within the cervical and thoracic region (arrows). The fluid was isointense to CSF on T1-weighted images. Interspinous ligamentous injury is present (not shown).

ment injury. Joint capsule fluid at the craniocervical junction was present in 32% ( $n = 28$ ), which was associated with capsular distention in 13% out of the 28 patients with joint fluid. Patients with restricted diffusion on brain MR imaging were associated with joint capsule fluid at the craniocervical junction (43% versus 11%,  $P = .0032$ ) (Fig 3). Bone marrow edema was present in 9% of the patients ( $n = 8$ ). Cord hemorrhage was seen in 5% ( $n = 4$ ) of the cases. Epidural fluid/epidural edema was present in 10% ( $n = 9$ ) (Fig 4). Interspinous ligamentous injury was present in 89% of patients with abnormal epidural fluid. Subdural hemorrhage in the cervical and upper thoracic spinal canal was present in 18% of the patients ( $n = 16$ ) and was always associated with intracranial subdural hemorrhage (Fig 5).

Parenchymal restricted diffusion on the brain MR imaging was identified in 65% of the patients ( $n = 58$ ). Patients with re-

stricted diffusion on brain MR imaging were associated with CSI by imaging (81% versus 41%,  $P = .0004$ ) (Fig 3). However, for patients with restricted diffusion in the brain, we did not find statistical evidence that different types of restricted diffusion distribution were associated with CSI by imaging ( $P = 1$ ) (Fig 6). Of the patients with restricted diffusion, diffuse distribution of the restricted diffusion was present in 70%, multifocal pattern in 15%, and focal pattern in 15%.

All patients had head CT performed at admission. Parenchymal injury was seen in 56% of the patients ( $n = 50$ ), of whom global parenchymal injury was seen in 76%. Normal head CT with no evidence of intracranial injury was

noted for 8 patients, and 3 of these patients had evidence of CSI. Of these 3 patients, 1 had parenchymal restricted diffusion on brain MR imaging and 2 showed no intracranial injury on MR imaging. Documentation of additional non-neurologic injuries allowed a diagnosis of NAT in the patients without evidence of AHT on either CT or MR imaging. Patients with parenchymal injury on CT were associated with spine injury by imaging (82% versus 51%,  $P = .0027$ ) (Fig 1). Patients with global parenchymal injury on head CT were associated with CSI by imaging (84% versus 57%,  $P = .0104$ ). Patients with global parenchymal injury on head CT were also associated with joint capsule fluid at the craniocervical junction (45% versus 22%,  $P = .0233$ ). Intracranial subdural hematomas were present in 85% of the patients ( $n = 76$ ). The most common pattern of subdural hematomas was hyperattenuated (44%). Mixed-attenuation subdural hematomas were present in 36% of the patients, and hypoattenuated subdural collections were present in 5%. There was no statistically significant association between subdural hemorrhage on head CT and spine injury on imaging. However, there was a statistically significant association between the types of subdural hematoma and spine injury by imaging, with mixed-attenuation and hyperattenuated subdural hemorrhage being more common in children with spine injury by imaging ( $P = .0253$ ). A follow-up CT was performed in 56 patients (63%), of which 21 (38%) showed redistribution of the subdural hemorrhage.

The skeletal survey was positive for fractures other than skull in 36% of the patients ( $n = 32$ ). Of the fractures found on skeletal survey, healing fractures were most common (47%). Skull fractures were present in 29% of the patients ( $n = 29$ ). Of the patients with skull fractures, linear skull fractures (18%) were more common than comminuted fractures (11%). There was no statistically significant association between presence of skull fracture on head CT and presence of spine injury on imaging.

Logistic regression with stepwise variable selection method was used to select the most predictive variables for each outcome of interest, including spine injury by imaging, joint capsule fluid at craniocervical junction, and presence of any ligamentous injury. Restricted diffusion on brain MR imaging was the most pre-

dictive variable of CSI on MR imaging ( $P = .0004$ ) and ligamentous injury ( $P = .0001$ ). Children with restricted diffusion on brain MR imaging were 6.22 (point estimate) times more likely to have CSI by imaging and 7.26 times more likely to have ligamentous injury as the finding on MR imaging (Fig 7). No other variables, including parenchymal injury on CT, presence of subdural hemorrhage on CT, and skull fracture, had a significant addition in prediction power. Restricted diffusion ( $P = .0057$ ) and age ( $P = .0390$ ) were the 2 most predictive variables of joint capsule fluid at the craniocervical junction.

## DISCUSSION

To date, this study includes the largest number of patients ( $n = 89$ ) with verified NAT, originating from a trauma registry, with CSI evaluated on MR imaging. Each of the patients' records were reevaluated independently, based on the criteria adapted from a classification schema developed by Feldman et al<sup>10</sup> in 2001, by medical providers trained and certified in child abuse pediatrics. The only patients included in this study were those who had a verified clinical diagnosis of NAT. Typically, children with clini-

cally suspected CSI are evaluated initially with cervical radiographs. In our series, we found that only 64% of the patients who had CSI by MR imaging had diagnostic-quality cervical radiographs, with few demonstrating abnormal findings.

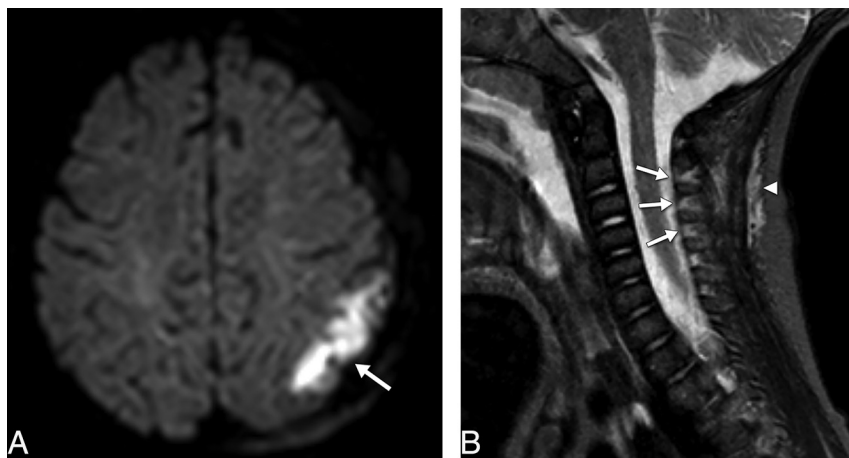
Cervical radiographs were performed at a tertiary pediatric hospital by technologists with experience in pediatric emergency radiography. This emphasizes both the difficulty in obtaining quality cervical radiographs in patients with NAT and the inherent low sensitivity of the technique in diagnosing ligamentous and soft tissue injury. It has been reported that cervical radiographs have a borderline sensitivity of 78% in the general pediatric trauma population, but this is compared with cervical CT, which is insensitive for soft tissue injury.<sup>11</sup> A relatively low incidence of skull fractures was also present in our patient group. This may be because of the lack of an impact injury, which has been reported to occur in NAT and the subset of children with AHT.<sup>12</sup>

Most patients in our study were infants and toddlers. Only 2 (2%) children were older than 3 years, and 73% were younger than 1 year of age. Only 43% of patients had MR imaging studies of superior quality. This highlights the challenge of performing MR imaging in this particular population, where many of the children are critically sick and/or unstable. The small size of the patients, presence of a cervical collar, and multiple life support devices complicate the image acquisition. Sagittal STIR sequences were found to be most useful for assessing the presence of CSI in this cohort, similar to previous reports.<sup>2,13</sup> Axial T2WIs were used to confirm cord edema and evaluate the integrity of the transverse ligament. Sagittal T1WIs and axial gradient-echo T2WIs were optimal for the evaluation of extra- and intramedullary hemorrhage, respectively.<sup>2,13</sup>

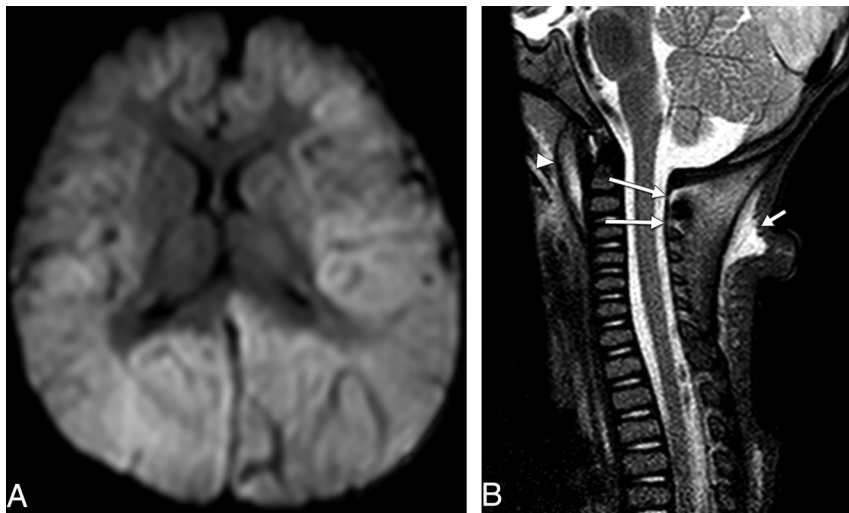
In our cohort, we found CSI by MR imaging in 69% of patients. Katz et al<sup>14</sup> examined the prevalence of cervical injury associated with head trauma from all causes in infants and found only 2 of the 905 infants (0.2%) in their cohort had spine injury; both of the infants had head injury secondary to NAT. The study by Katz et al<sup>14</sup> study was limited by the small number of patients evaluated by MR imaging (1%). A study of children with AHT by Kadom et al<sup>14</sup> found 36% of 38 children had CSI by MR imaging. Choudhary et al<sup>6</sup> found a higher incidence (78%) in children evaluated with AHT and a higher frequency of CSI compared with an accidental cohort. The study also reviewed cervical MR imaging examinations in a nontraumatic cohort and found only 5 of 70 patients had abnormal imaging examinations, with 4 explained by other mechanisms. Only 1 patient had imaging findings not readily explained, and the authors postulated tonic-clonic seizures as a potential etiology. This study offers evidence that the findings demonstrated on cervical MR imaging are not normal variants and, in fact, relate to pathology. The latter 2 studies found an association between brain injury and CSI. Injury of the tectorial membrane was uncommon in our group (3%) and has not been previously reported in the



**FIG 5.** Three-month-old patient. Sagittal midline T1WI shows intracranial and intraspinal T1 hyperintense subdural hemorrhage (arrows).



**FIG 6.** Seven-month-old patient. A, Axial DWI shows focal restricted diffusion in the left parietal lobe (arrow). B, Sagittal midline STIR image demonstrates interspinous ligamentous injury (arrows) and injury to the nuchal ligament (arrowhead).



**FIG 7.** Seven-month-old patient. A, Axial DWI shows diffuse cerebral restricted diffusion, worse on the left. There is mild midline shift, left to right, caused by a left hemispheric convexity subdural hemorrhage (not shown). B, Sagittal midline STIR image demonstrates interspinous (long arrows) and nuchal ligament injury (short arrow). There is also prevertebral edema (arrowhead).

setting of NAT.<sup>4,6</sup> Although not evaluated with MR imaging, injury to the tectorial membrane may be inferred in the study by Silvera et al,<sup>15</sup> where 14% of their abusive head trauma cohort had retroclival epidural hemorrhage. Most of the ligamentous injuries in our cohort, as well as previously reported studies,<sup>4,6</sup> were cervical interspinous and nuchal ligament injuries.

Abnormal capsular fluid was seen in 32% of patients, with distention seen in 13% of these patients. This finding was reported by Choudhary et al,<sup>6</sup> but was more commonly seen in our patient group (22% versus 32%). Most of our patients with abnormal capsular fluid were infants (mean age, 5.6 months), highlighting that the fluid at the craniocervical junction may be related to a flexion/hyperextension mechanism of injury. Interestingly, marrow edema was significantly associated with an older age group (mean age, 14.9 months). There also was a significant relationship between restricted diffusion on brain MR imaging and capsular fluid at the craniocervical junction. The presence of CSI as diagnosed with MR imaging may suggest a traumatic cause to findings demonstrated on head imaging and, thus, is potentially important in the investigation of these cases. It is important to note that 3 cases of CSI were found in 8 patients with a normal head CT.

Spinal subdural hemorrhage was seen in 18% ( $n = 16$ ) of patients in our study, all of whom also had subdural hemorrhage on brain CT. This finding has been noted by other authors and may be related to redistribution of intracranial blood products into the spinal canal.<sup>5,16</sup> Redistribution of intracranial subdural blood was commonly found in our group of patients. Imaging the entire spine may provide an advantage over imaging the cervical spine alone because hemorrhage has been shown to layer within the subdural space of the thoracolumbar spine in cases of abusive head trauma. None of our patients had subdural hemorrhage confined to the spine; however, the presence of spinal subdural hemorrhage is uncommon in the accidental trauma population and may suggest NAT.<sup>5</sup>

Mixed-attenuation and hyperattenuated intracranial subdural hemorrhage were statistically associated with CSI by MR imaging.

Hypoattenuated collections may be caused by a more remote traumatic event and were not associated with CSI, possibly because of normal resolution of the MR imaging findings. Spinal epidural fluid was seen in 10% ( $n = 9$ ) of the patients and was commonly associated with interspinous ligamentous injury. This finding has been described previously as a possible postmortem artifact.<sup>7,17</sup> We suggest that abnormal epidural fluid collections are likely the result of trauma; however, a history of a recent lumbar puncture should be excluded before attributing epidural fluid collections to trauma.<sup>18</sup>

Restricted diffusion in brain MR imaging had a very strong association with spine injury and any ligamentous injury. This finding highlights the importance of obtaining cervical spine MR imaging in

patients with abnormal restricted diffusion on brain MR imaging. Future studies would help evaluate any association between the pattern of restricted diffusion in the brain and presence of spine injury. We did not find an association between the type of parenchymal injury and CSI; however, this may be because of the predominance of diffuse parenchymal injury and the relatively small number of cases with focal or multifocal parenchymal injury. Global parenchymal injury on CT was statistically associated with spine injury by MR imaging. These results support the hypothesis that injury to the cervical spine can result in occult injury to the brain stem or upper cord, resulting in a hypoxic-ischemic insult.

Limitations of our study include a retrospective design and a case selection bias, in that patients with lower severity of injuries or normal head CT may not have had brain or cervical MR imaging performed. The patients included in our study were more likely to have experienced severe trauma, with most admitted to the intensive care unit. Another challenge was the lack of a uniform protocol for spine imaging, along with the fact that the presence of comorbidity made early MR imaging difficult to perform. Finally, to date, there is no published certified tool to use when determining NAT. Our study employed the expertise of the medical providers trained and certified in child abuse pediatrics, who based their diagnosis on a classification schema from a paper published by Feldman et al<sup>10</sup> in 2001.

## CONCLUSIONS

The children we evaluated with cervical MR imaging for NAT had a high incidence of CSI. Children with head CT or MR imaging evidence of parenchymal injury or restricted diffusion on brain MR imaging have an increased incidence of CSI diagnosed by MR imaging. Although the presence of parenchymal injury is associated with CSI in NAT, a large number of patients without parenchymal injury had evidence of CSI on MR imaging. Especially important is the small group of children who had normal head imaging and evidence of CSI. Our evidence suggests that including cervical spine MR imaging should be included as part of the armamentarium of tests performed



while working up a child with NAT. The presence of CSI may be additional evidence of a traumatic etiology. In addition, performing cervical MR imaging would further enhance the understanding and characterization of spinal injuries in children with NAT.

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