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CHILD ABUSE IMAGING

Spinal ligamentous injury in abusive head trauma: a pictorial review

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Abstract

There is growing evidence of spine injury in abusive head trauma (AHT). Historically, spine injury was considered rare in AHT because of a lack of attributable clinical symptoms or signs and a lack of advanced imaging. Increased use of MRI in AHT has been instrumental in helping identify evidence of ligamentous injuries of the spine. These findings can be difficult to identify on autopsy because of the size and location of the ligaments. Because spinal injury in AHT mostly involves ligamentous and soft tissues and only rarely involves bony fractures, more than 90% of the injury findings are missed on CT or radiography of the spine. Investigation of these findings and the injury patterns should lead to a better understanding of the mechanism of spinal injury. In this pictorial review, we describe the various manifestations of spinal ligamentous injury in AHT, as seen on MRI, in children younger than 48 months.

Keywords Abusive head trauma · Child · Infant · Magnetic resonance imaging · Nuchal ligament · Radiology · Spinal ligament injury · Spine

Introduction

Abusive head trauma (AHT) is one of the leading causes of morbidity and mortality in children. The clinical presentation of children with head trauma varies from nonspecific symptoms to an abrupt collapse [1]. Clinical neurologic assessment of an infant's spine injury can be challenging, and this can be further complicated by coexistent significant intracranial injury, which can mimic or mask spinal injury [2]. These factors lead to an under-appreciation of spinal injury. If we review the historical literature, spinal injury was considered rare [3–5]. This is not surprising because spinal injuries were masked clinically and the primary imaging modalities of investigation — historically CT and radiography — did not show significant abnormalities. But recent literature, based primarily on MRI findings, has demonstrated that evidence of spinal injury, whether direct or indirect, is fairly common [2, 6–8]. In this pictorial review, we describe the various manifestations of spinal ligamentous injury in AHT, as seen on MRI, in children younger than 48 months.

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Anatomy

To accurately diagnose spinal ligamentous injury in children, it is vital to understand that the anatomy of an immature spine is different from that of a mature spine. These differences can result in vastly different clinical presentations and imaging findings, even with similar mechanisms of injury. Infants have a larger head relative to their body mass, weak neck muscles, large subarachnoid spaces, a thin and pliable skull, and a relatively flat skull base [2, 9]. The large head of an infant can comprise approximately a third of the total body weight. Large head size in combination with weak neck muscles creates the potential for severe craniocervical and cervical spinal injury. The incompletely ossified infant cervical spine has shallow horizontally oriented facet joints, underdeveloped spinous processes, physiological anterior wedging of the vertebral bodies, and immature lax supporting ligaments. All these variables place the infant's ligaments and spinal cord at an increased risk for injury, particularly at the craniocervical junction, which houses the cervicomedullary junction [10, 11]. In addition, there is greater flexibility of the spinal column relative to the spinal cord because of ligamentous laxity, putting the cervical spinal cord at an increased risk for stretching or transient injury from vertebral body subluxation.

Imaging findings

Confessions have given us an insight into the various mechanisms of injury in abusive head trauma. Predominantly, it involves shaking with or without impact injury to the head and neck [12–14]. The most consistently identified imaging findings in AHT include posterior suboccipital muscle and ligamentous injuries [2, 6]. In more severe injuries, anterior ligamentous structures and bony injuries might also be identified.

Posterior suboccipital muscle and ligamentous complex injury

These include larger structures such as the nuchal ligament and smaller ligamentous structures such as the atlanto-axial and atlanto-occipital membranes, interspinous ligaments and capsular ligaments of occiput–C1 and C1–C2 articulations.

The nuchal ligament is a bilaminar fibroelastic intermuscular septum and has two components — the anterior membranous lamellar portion and posterior cord-like funicular segment. The lamellar portion is a membranous structure attached to the median part of the external occipital crest, the posterior tubercle of C1 and the medial aspect of bifid spines of the cervical vertebrae [15]. There is also a midline attachment to the posterior dura at the atlanto-axial and atlanto-occipital levels [16]. These membranes act as a septum for bilateral attachment of cervical muscles and their sheaths. The membranes fuse posteriorly to form a cord-like superficial structure (funicular segment), which extends from the posterior occipital protuberance to the spinous process of C7 (Fig. 1) [15]. The lamellar membrane contains fat and on short tau inversion recovery (STIR) sequence should appear predominantly hypointense. If injury is present, T2 hyperintensity is evident in this region along with fatty stranding on T1 or T2 sequence (Figs. 2, 3 and 4).

The posterior atlanto-axial and atlanto-occipital membranes are thin membranous structures posterior to the dura

Fig. 1 Normal appearance of nuchal ligament and suboccipital region on MRI. **a** Sagittal T1-W image of the cervical spine in a 6-month-old boy with no history of trauma shows fat-containing hyperintense lamellar membranous portion (*short arrow*) and hypointense funicular segment (*long arrow*) of the nuchal ligament. **b** Sagittal T2-W image of the cervical spine in the same 6-month-old boy with no history of trauma shows fat-containing hyperintense lamellar membranous portion (*small arrow*) and hypointense funicular segment (*large arrow*) of the nuchal ligament. **c** Sagittal short tau inversion recovery MR image in a 4-month-old boy with no history of trauma demonstrates the hypointense suboccipital region including lamellar and funicular segments of the nuchal ligament. T2 hyperintensity is noted along the anterior aspect of the interspinous ligaments (*arrow*), representing normal venous plexus. These should not be misconstrued as evidence of injury

Fig. 2 Abusive head trauma (AHT) in a 3-month-old boy. **a** Initial presentation of this boy was with seizure at 3 months of age. Sagittal T1-W MRI of the cervical spine demonstrates a normal nuchal ligament and suboccipital soft-tissue structures. **b** His second presentation, at 5 months of age, with AHT. Sagittal T1-W MR image of the cervical spine demonstrates stranding of the fat in the region of lamellar membrane of the nuchal ligament and swelling of the funicular segment of the nuchal ligament (*long solid arrow*). Hyperintense subdural hemorrhage is identified in the supratentorial compartment (*dashed arrow*) and posterior fossa and extends through the craniocervical junction (*arrowhead*) and spinal canal (*short arrows*). **c** Second presentation at 5 months of age with AHT. Sagittal short tau inversion recovery MR image of the cervical spine demonstrates extensive hyperintensity of the nuchal ligament and suboccipital region along with attenuation of the upper segment of the nuchal ligament (*long arrow*), confirming evidence of injury. Hypointense subdural hemorrhage is identified in the supratentorial compartment (*upper short arrow*) and spinal canal (*lower short arrow*)

extending between the C1–C2 and occiput–C1, respectively. The injury to the membrane itself might be difficult to identify unless high-resolution images of this region are obtained. But the presence of T2 hyperintensity in this region represents evidence of acute injury. The imaging features of chronic injury, with thickening of these membranes, might be seen in older children with chronic craniospinal instability from skeletal dysplasia (Fig. 5).

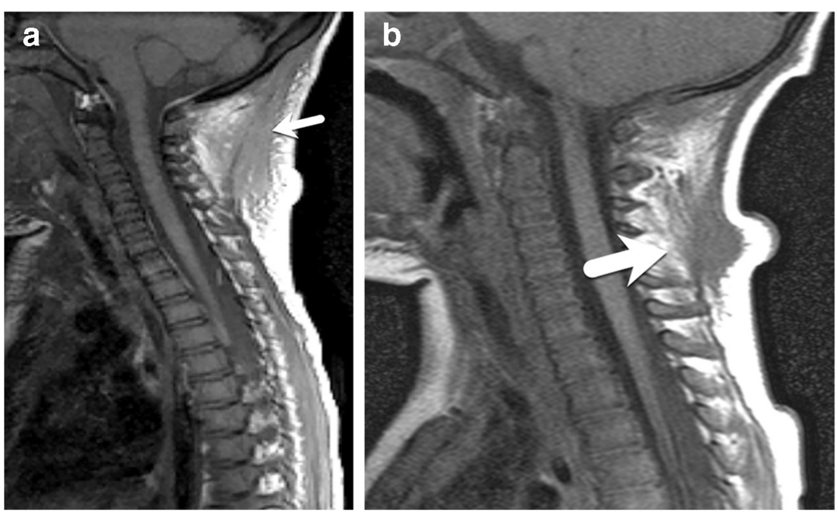

Fig. 3 Various patterns of nuchal ligament injury on T1-W MR sequence in multiple children with abusive head trauma. **a** Sagittal T1-W MR of the cervical spine in a 2-year-old girl demonstrates hyperintense hematoma along the upper segment of the nuchal ligament (*arrow*), near its attachment to the occipital bone. The nuchal ligament is poorly defined in this region. There is associated stranding of the lamellar membrane. **b** Sagittal T1-W MR image of the cervical spine in a 1-year-old girl demonstrates hyperintense (relative to paraspinal musculature) hematoma along the lower segment of the nuchal ligament (*arrow*) near its attachment to the C7 spinous process. The nuchal ligament is poorly defined in this region, and there is associated stranding of the lamellar membrane

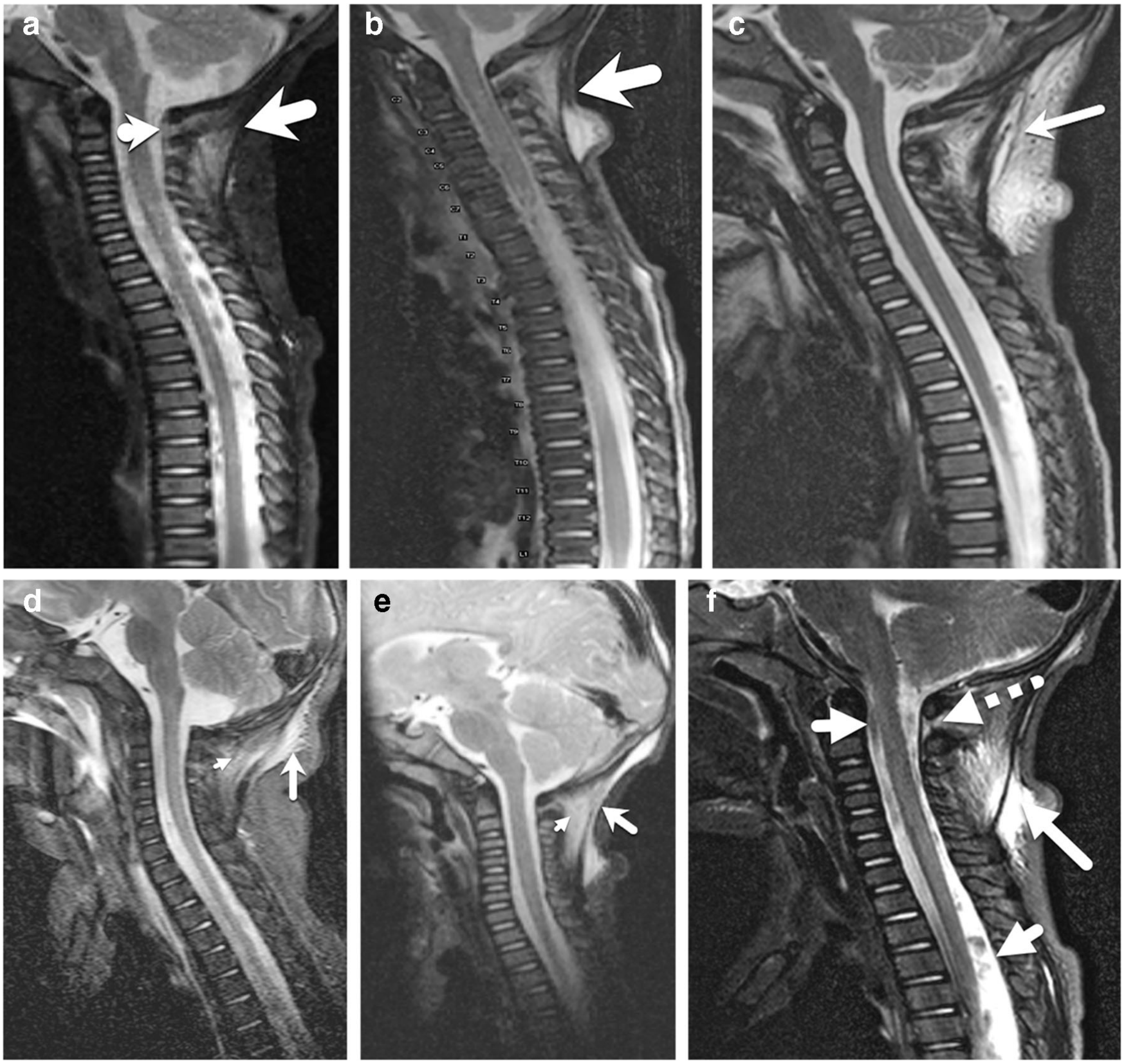

Fig. 4 Various patterns of nuchal ligament injury on short tau inversion recovery (STIR) MRI in multiple children with abusive head trauma. **a** Sagittal STIR image of the cervical spine in a 6-month-old boy demonstrates T2 hyperintensity of the nuchal ligament (*large arrow*) as well as along the atlanto-occipital and atlanto-axial membrane (*small arrow*). Note the absence of significant subcutaneous edema. **b** Sagittal STIR image of the cervical spine in a 2-month-old girl demonstrates T2 hyperintensity of the nuchal ligament (*arrow*) as well as along the atlanto-occipital and atlanto-axial membrane. There is also evidence of injury to the interspinous ligaments. Edema is evident, particularly along the thoracic spine region. **c** Sagittal STIR of the cervical spine in a different 2-year-old girl demonstrates extensive injury of the suboccipital soft-tissue structures. There is a collection along the nuchal ligament (*arrow*). Note the edema along the lamellar membrane extending deep to the atlanto-axial membrane. There is also extensive subcutaneous edema. **d** Sagittal STIR of the cervical spine in an 11-month-old boy demonstrates evidence of injury to the nuchal ligament along its upper extent near its attachment to the occipital bone (*long arrow*). The nuchal ligament is poorly defined in this region and is relatively T2 hyperintense and attenuated. Evidence of injury to the lamellar membrane (*short arrow*) is also identified. **e** Sagittal STIR of the cervical spine in a 5-month-old boy demonstrates evidence of injury to the nuchal ligament along its upper extent near its attachment to the occipital bone (*long arrow*). The nuchal ligament is poorly defined and is relatively T2 hyperintense and attenuated. Note evidence of injury to the lamellar membrane (*short arrow*). **f** Sagittal STIR image of the cervical spine in a 1-year-old girl demonstrates hematoma along the lower extent of the nuchal ligament along with its attenuation (*long solid arrow*). There is also evidence of edema along the atlanto-axial membrane (*dashed arrow*). Focal areas of irregular-shape linear and rounded areas of hypointensity are evident in the spinal canal anterior to the spinal cord proximally (*upper short arrow*) and posterior to the cord distally (*lower short arrow*). These represent cerebrospinal fluid pulsation artifact and should not be mistaken for spinal subdural hemorrhage

Similarly, T2 hyperintensity along the capsular ligaments of occiput–C1 and C1–C2 articulation is frequently identified, and this represents evidence of injury. Distraction injury is suspected when there is also an increase in joint space with an effusion. Mild distraction injury, rather than frank dissociation, is more commonly seen in AHT (Fig. 6). Joint effusion

Fig. 5 Spondyloepiphyseal dysplasia in a 2-year-old boy with no history of trauma or suspicion of abuse. **a, b** Sagittal T2-W MR images in extension (**a**) and flexion (**b**) positions of the cervical spine demonstrate instability at the craniocervical junction with compression of the spinal canal on the flexion view. Also identified is the markedly thickened atlanto-axial membrane (*arrow*), likely representing evidence of chronic injury resulting from atlanto-axial instability. Diffuse platyspondyly is also noted

and mild distraction injury might also be identified on soft-tissue coronal or sagittal reconstructions of spine CT.

Muscle edema in the suboccipital region might be symmetrical or asymmetrical and represents evidence of partial injury or contusion (Fig. 7). It is important to realize that vascular plexus is normally present in the anterior interspinous region and it should not be confused with edema or hematoma (Fig. 1). Also, if the fat suppression is not optimum or homogeneous, artifacts can mimic edema. Other significant injury patterns include injury to cord, nerve roots or dural perforation.

Anterior ligamentous injury

Although less common, anterior spinal injuries are known to occur in children with AHT. The ligamentous complex that supports the anterior spinal cord consists of the apical and alar ligaments of the dens, the anterior and posterior longitudinal ligament, the cruciform ligament and the tectorial membrane. Injuries to these are seen with a primary extension injury (Fig. 8).

Bony injury

Vertebral fractures are relatively less common and might be identified on skeletal surveys (Figs. 8 and 9). Injury to the thoracic or lumbar spine is also relatively uncommon.

Injury to the tectorial membrane

Partial or complete tear of the tectorial membrane can result from a significant injury to the craniocervical junction. Apart from attenuation or frank disruption of the tectorial membrane, stripping of the membrane from the clivus might also be identified. This can be associated with retroclival hematoma. Subdural hemorrhage can also be identified in the retroclival region in the presence of posterior fossa SDH. If the collection is deep to the tectorial membrane (extends from the mid-clivus to base of C2) the collection is epidural, whereas if the collection is superficial to the tectorial membrane but deep to the arachnoid, the collection is deemed subdural. Like spinal ligamentous injury, retroclival hematomas were once considered rare in the setting of AHT. However, retroclival collections can also be quite difficult to appreciate on

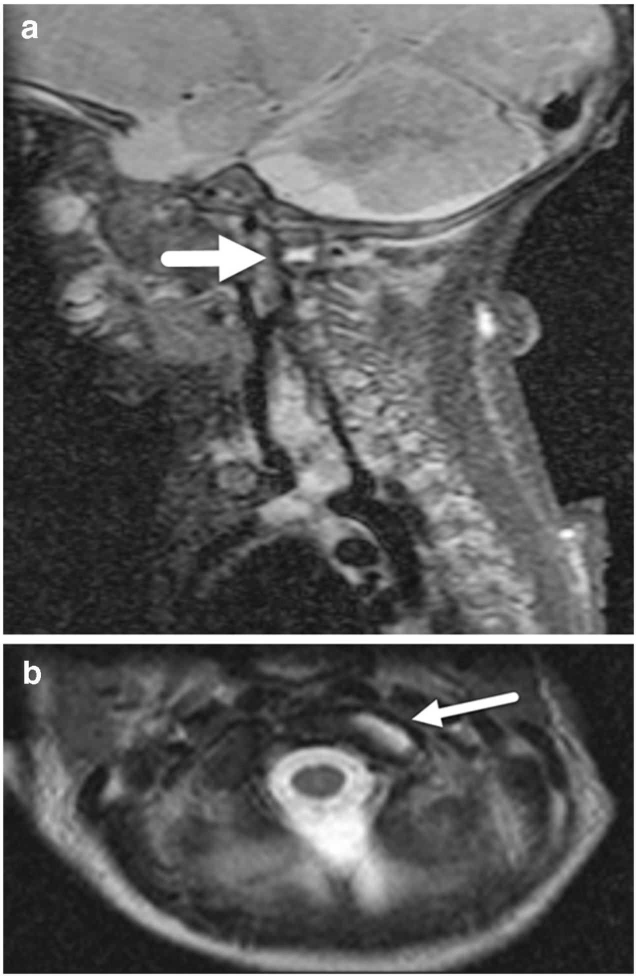

Fig. 6 Capsular injury in a 4-month-old boy with abusive head trauma. **a** Sagittal short tau inversion recovery (STIR) MR image of the cervical spine demonstrates evidence of capsular injury (*arrow*) of the atlanto-axial joint on the left side. **b** Axial STIR of the cervical spine confirms the capsular injury findings (*arrow*)

radiographs or CT and might only be well demonstrated on MR imaging. In a retrospective study of retroclival collections associated with abusive head trauma, the detection was higher on MRI (85%) as compared to CT (38%) [17].

Literature review

Cervical spine ligamentous injuries (predominantly the nuchal, atlanto-occipital and atlanto-axial ligaments) are almost twice as common in AHT (78%) as compared to accidental trauma (46%) [2]. It is important to note in this study by Choudhary et al. [2] that in cases of AHT the cervical spine MRI was routinely obtained, whereas in the cases of accidental trauma the imaging was only obtained if there was a clinical concern for spine injury. The differences were found to be statistically significant, showing a high incidence of ligamentous injury in children with AHT when compared to cases with either accidental trauma or nontraumatic injuries. This might reflect the repetitive nature of the shaking injury or the extreme violence of the injury [12].

Among AHT cases, ligamentous injury was identified in 36% (Kadom et al. [6]), 32% (Governale et al. [7]), 59% (Rabbitt et al. [8]), 31% (Henry et al. [18]) and 67% (Jacob et al. [19]). The variability of reported ligamentous injuries in AHT as identified on MRI in the more recent literature likely relates to patient selection for imaging or retrospective reviews (variably included age groups and imaging modalities), or variable imaging techniques. Further reviews are important to advance our knowledge.

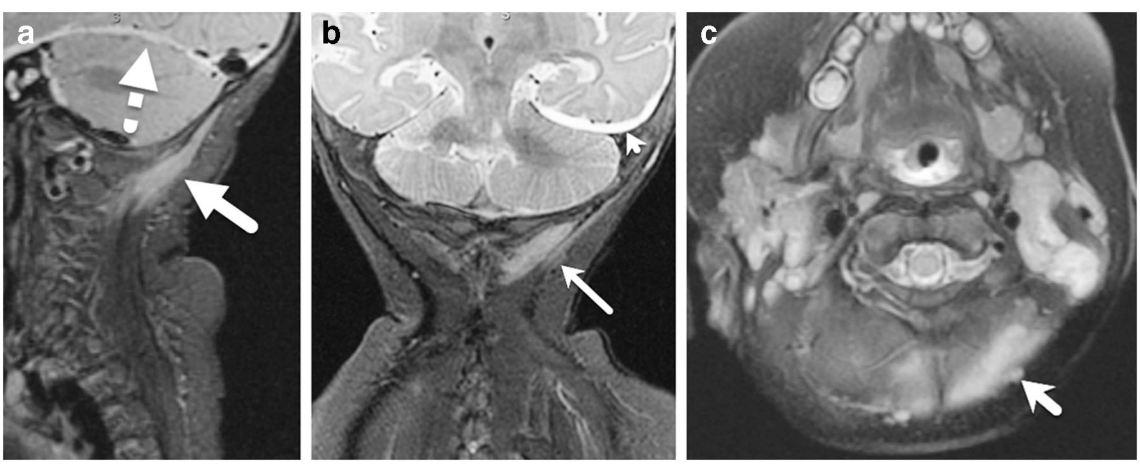

Fig. 7 Suboccipital musculature injury in a 4-month-old girl with abusive head trauma. **a** Sagittal short tau inversion recovery (STIR) MR image of the cervical spine demonstrates evidence of injury to the suboccipital musculature, which is primarily asymmetrical in nature and centered over the left suboccipital region (*solid arrow*). This might represent asymmetrical force of the injury or contusion from an impact injury. A T2-hyperintense subdural hemorrhage (SDH) is identified along the left temporal lobe (*dotted arrow*). **b** Coronal STIR image of the cervical spine also demonstrates evidence of asymmetrical injury to the suboccipital musculature, centered over the left suboccipital region (*long arrow*). This image also identifies the T2-hyperintense SDH along the left temporal lobe (*short arrow*). **c** Axial STIR image of the cervical spine demonstrates similar findings of suboccipital musculature injury centered over the left suboccipital region (*arrow*)

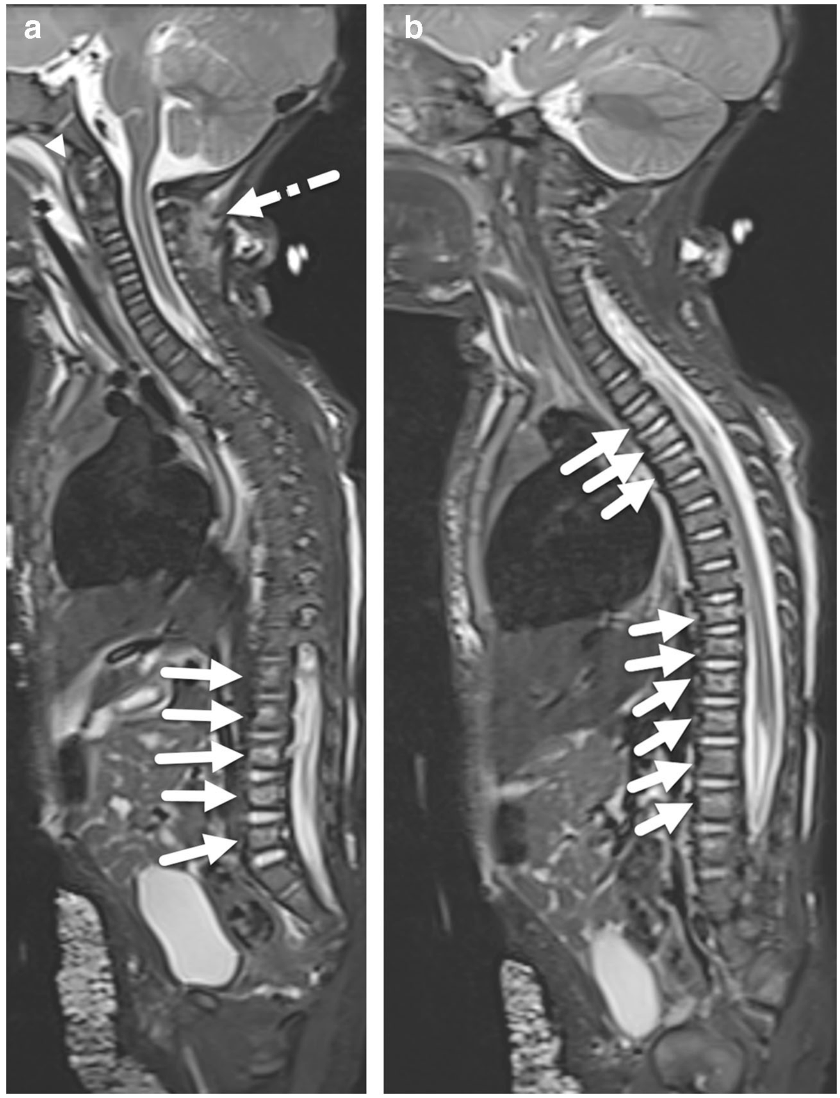

Fig. 8 Anterior ligamental injury and spinal compression fractures in a 3-month-old boy with abusive head trauma. **a** Sagittal short tau inversion recovery (STIR) MR image of the complete spine demonstrates anterior ligamental injury at the craniocervical junction with prevertebral soft-tissue swelling (*arrowhead*). Note the posterior ligament injury involving the nuchal ligament (*dashed arrow*). Multilevel compression fractures of the lumbar vertebra are identified (*solid arrows*). **b** Sagittal STIR image of the complete spine also demonstrates multilevel compression fractures of the thoracic and lumbar vertebrae (*arrows*)

Hypoxic–ischemic injury and ligamentous injury of the neck

There is also a statistically significant correlation between hypoxic–ischemic injury of the brain and ligamentous injuries of the spine in cases of AHT [2, 19]. One hypothesis has been that spinal cord and/or brainstem injury results in apnea or disordered breathing, secondarily leading to hypoxic–ischemic brain injury [2, 20].

Clinical practice

The practice of routine MR imaging of the cervical spine is continuing to evolve at multiple institutions. Some institutions obtain it routinely, whereas others obtain it only if significant brain injury is present. The discussion is usually centered on the clinical utility of MR imaging of the cervical spine, the clinical management of the stable non-bony soft-tissue ligamentous injury of the spine, the cost of imaging and the timing of obtaining the study. In some cases, limited availability of sedation resources or access to MRI can be an additional challenge. In presence of ligamentous injuries without unstable bony fractures, some neurosurgical institutes manage them actively with a soft neck collar [21, 22]. To answer the concern regarding the cost of the study, first, the study provides additional information regarding a plausible mechanism of injury. Second, it helps exclude differential diagnoses, potentially a cost-saving measure on its own [23]. Last, the management approach should be contrasted with clinical management standards of other disease processes. If a clinical finding can be identified to confirm a diagnosis, explain the etiology or help exclude other potential causes, would it be part of your routine clinical practice? MRI of the cervical spine in AHT

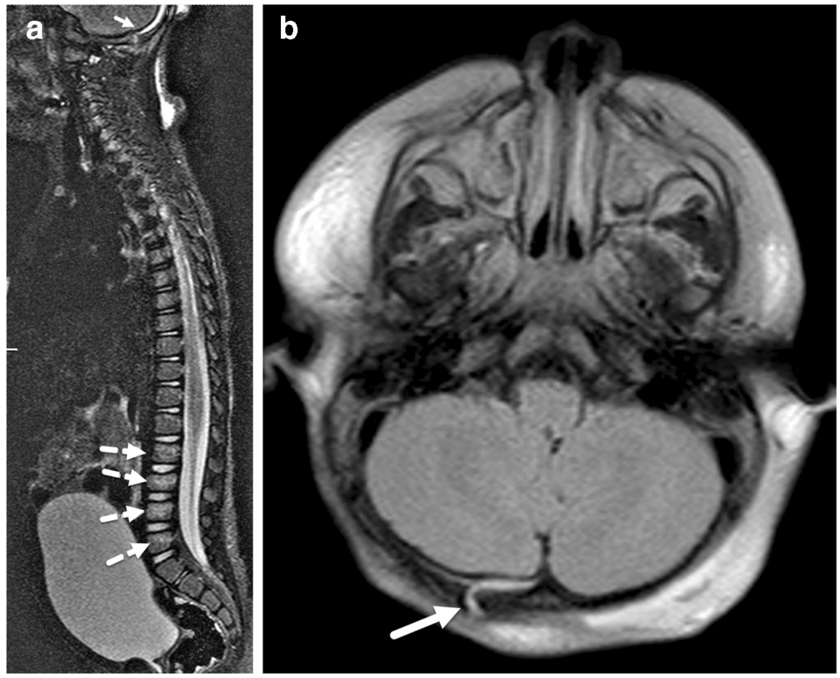

Fig. 9 Spinal fractures in a 2-year-old boy with abusive head trauma. **a** Sagittal short tau inversion recovery MR image of the complete spine demonstrates mild compression fracture of lower lumbar vertebrae (*dashed arrows*). A mildly displaced occipital fracture is also identified (*solid arrow*). **b** Axial fluid-attenuated inversion recovery sequence demonstrates the right occipital fracture with epidural collection (*arrow*)

similarly adds significantly to our understanding of AHT mechanism of injury, helps confirm a diagnosis of AHT, excludes potential differential diagnoses and provides clear clinical value in the immediate management of the child. In addition, it helps in the determination of the eventual disposition of the child and care of the siblings.

Conclusion

Spinal injury is common in AHT and predominantly involves the craniocervical junction in most children. The injury also predominantly reflects a flexion injury mechanism of the soft-tissue structures, particularly involving the posterior suboccipital region. Because the spinal injury of AHT mostly involves ligamentous and soft tissues and only rarely involves bony fractures, more than 90% of the MRI injury findings are missed on CT or radiographs of the spine.

Compliance with ethical standards

Conflicts of interest Dr. Choudhary is a medical expert in child abuse cases.

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