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REVIEW

Spinal lesions caused by abusive trauma in young children

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Abstract

Background and purpose Spinal lesions are increasingly recognized as an integral part of the child abuse spectrum; however, the description of lesions, their biomechanics, true incidence, clinical impact, and medicolegal implications are poorly understood.

Material and methods We report from the literature and our personal experience on abusive spinal lesions (ASL) in children under 3 years, compared with cases of abusive head injuries (AHI) without spinal lesions on the one hand and with accidental spinal lesions on the other.

Results Between 2002 and 2021, we collected 12 observations of ASL, 4 male and 8 female. These were compared with 338 cases of infants having AHI without ASL and 18 cases of accidental spinal trauma in the same age group. Fractures were found in 10 cases of ASL: wedge fracture in 9, and complete disruption with paraplegia in one, which required emergency reduction and stabilization with a good motor recovery. Two patients had intraspinal hemorrhagic lesions without fracture, associated in one case with tetraplegia which contributed to the fatal outcome. ASL affected girls more often and had a more severe clinical presentation; more than half of ASL involved the lumbar levels, which were unaffected in accidental traumas.

Conclusions ASL are not exceptional, and their presence corroborates cranial lesions indicating child abuse. Two etiologies emerge from this study: wedge fractures and cervical spinal cord lesions caused by shaking and the rare thoraco-lumbar dislocation indicating a particularly violent assault. Systematic MRI study of the spine is warranted in cases of child abuse.

Keywords Shaken baby syndrome · Silverman syndrome · Biomechanics · Medicolegal inquiry

Introduction

Pediatric neurosurgeons are mostly confronted with child abuse because of abusive head injuries (AHI) and exceptionally because of clinically eloquent spinal lesions. Looking back in history, however, fatal abusive spinal lesions (ASL) were already described in 1860 by Ambroise Tardieu in his observation XXVII [1]. AHI became largely documented after the advent of roentgenology, with the pioneering publications by Kempe et al. and Caffey [2, 3], describing the beaten child syndrome (BCS) and the shaken baby syndrome (SBS) respectively. However, it is only after MRI became widely available that ASL became recognized as an integral part of the shaken baby syndrome (SBS) and beaten child syndrome (BCS) [4].

However, the description of ASL in medical literature varies widely, according to the source of data. Surgeons often consider that ASL represent a marginal subset of spinal traumatic lesions [5, 6], often published as case reports [7, 8], while neuroradiologists consistently report a high prevalence of intradural hemorrhagic lesions on systematic MRI [9–11]; however, the clinical impact of these lesions is unclear. The type of lesions and their relation to shaking or beating and their impact on the overall outcome as well as their medicolegal implications are also poorly documented in literature. We decided to review the available literature and our clinical data on ASL.

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Material and methods

We analyzed retrospectively the data collected over the last 20 years in our institution. The diagnosis of child abuse was made during multiprofessional meetings and based on characteristic traumatic cranial and extracranial lesions, the context and circumstances, and after exclusion of other possible causes; this protocol was in accordance with a consensus document published in the meantime [12]. The standard explorations included fundoscopy by an ophthalmologist, skeletal studies looking for traumatic lesions, and biological studies to exclude non-traumatic causes. Although cerebral MRI was performed whenever feasible, spinal MRI became a standard procedure only progressively over the course of the study. We collected all available data regarding clinical and radiological findings and the clinical outcome.

Results

We collected 12 observations of ASL, 4 male and 8 female, aged 1.9 to 31 months (median 14.4). Nine of these patients were aged less than 2 years, representing 2.51% of cases of abusive trauma in this age group. ASL also represented 4.12% of all traumatic spinal lesions in children diagnosed in our institution during the same period, rising to 38.7% of spinal traumatic lesions under the age of 3 years; abuse was thus the leading cause of spinal trauma in this age group.

Among these patients, 10/12 underwent cerebral MRI; however, only 4 patients underwent spinal MRI. The diagnosis of ASL was made on a CT scanner in 4 cases and on plain skeletal X-rays in 4. In addition, one patient died, and autopsy findings could be confronted with MRI (Fig. 1).

Antecedents

The M/F ratio was markedly different in the ASL group (0.5) compared with the control group (1.75); the difference was statistically significant (Fisher's exact test $p = 0.034$). The two groups showed no significant difference regarding the familial social and psychiatric antecedents; however, perinatal antecedents were less frequent in the children with spinal lesions (chi-square test $p = 0.015$).

Clinical presentation

The clinical presentation was severe in the majority of cases, mostly on account of the associated AHI: 8/12 (67%) were admitted in the intensive care, 7 because of seizures, and 6 because of coma; in the control group, only 43% were admitted in intensive care; the difference was statistically significant (Fisher's exact test $p = 0.007$). Two patients had clinical findings caused by spinal cord damage: one was paraplegic on admission, although her vigilance was preserved and she had no seizures (Fig. 2); another was in deep coma with extensive cerebral ischemic damage, which was considered to result at least in part from apnea caused by cervical spinal cord damage (Fig. 1). In the other 10 patients, the ASL were found during systematic screening. These 10 patients had no specific clinical presentation: although pain was almost constant on admission in alert patients, it could not be ascribed particularly to spinal lesions and subsided rapidly.

Spinal lesions

The lesions were cervical in one case, upper thoracic in 4, thoraco-lumbar in 5, and lower lumbar in 2; overall, in 7/12 patients, the lesions involved the lumbar segment (Fig. 3). Skeletal lesions were present in 10 cases: a mild wedge corporeal fracture in 9 (fig. 1) and a complete avulsion of the discal plate with disruption of the ligaments and L1-L2 posterior luxation in one case (Fig. 2A–C). Significant epidural hemorrhage was identified in two cases, on MRI in one case (Fig. 4B) and at autopsy in another. Spinal cord damage was identified on MRI in 2 cases, confirmed by autopsy in one of these. By comparison, accidental spinal traumatic lesions were only cervical or cervico-thoracic, including SCIWORA in 43% of cases, and presented with severe neurological deficit in 50% of cases and 29% mortality.

Other lesions

Eight patients with ASL (67%) had retinal hemorrhages and 5 (42%) had bruises; the proportions were very similar in the control group. Six patients (50%) were diagnosed with SBS, and 6 with BCS; the distribution between SBS and BCS was also similar in the control group.

Management of spinal lesions and outcome

As already mentioned, one patient died shortly after admission. One patient required reduction and stabilization in emergency, followed by a brace (Fig. 2D and E); two others were treated with a brace; the 8 other surviving patients were treated conservatively. The mean follow-up of survivors was 21.1 months (0.7 to 79); among these, 7 had a normal life, 2 had mild sequelae, and 1 had severe sequelae; all sequelae were the consequences of the cerebral and ocular lesions; none were related to the spinal lesions.

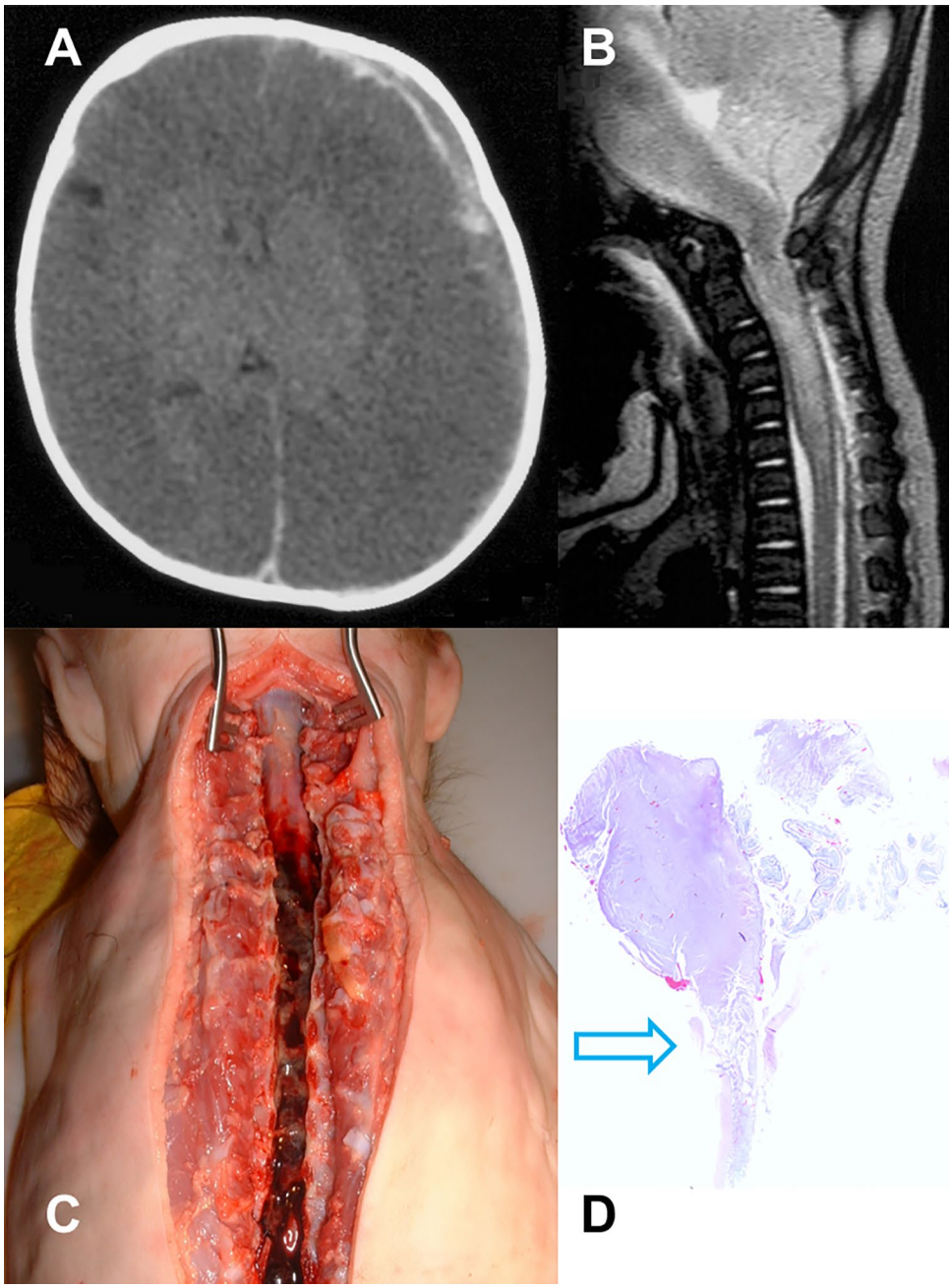

Fig. 1 Correlation between imaging and autopsy findings in a child who died of severe cerebral ischemic lesions. **A** Axial CT scanner showing a left-sided acute subdural hematoma with mild meningeal bleeding along the falx and extensive bilateral hypodensity (big black brain). **B** T2-weighted MRI, sagittal view, showing severe edema and swelling of the upper cervical cord. **C** At autopsy, total laminotomy shows a cervicothoracic epidural hematoma. **D** Pathology of the cervicomedullary junction showing almost complete disruption, in good correlation with MRI. In this patient, cerebral ischemic lesions could be ascribed, at least in part, to cervico-bulbar lesions causing apnea

Discussion

Our study reports on a rare condition, and the collection of data spans two decades. This accounts for discrepancy in the management of the patients; in particular, while the number of patients explored with cerebral MRI increased steadily, spinal MRI became a routine only recently. This explains why intraspinal hemorrhage is much more frequent in the literature [4, 9–11]. By contrast, almost all patients underwent skeletal survey with plain X-rays, explaining why wedge corporeal fractures were prevalent among ASL in our series.

Epidemiology

The prevalence of ASL is highly variable in literature. Most surgical publications state that it is a rare occurrence, accounting for 0.5 to 8% of spinal traumatic lesions [5, 6, 13]. However, if we focus on infants and toddlers, among whom spinal

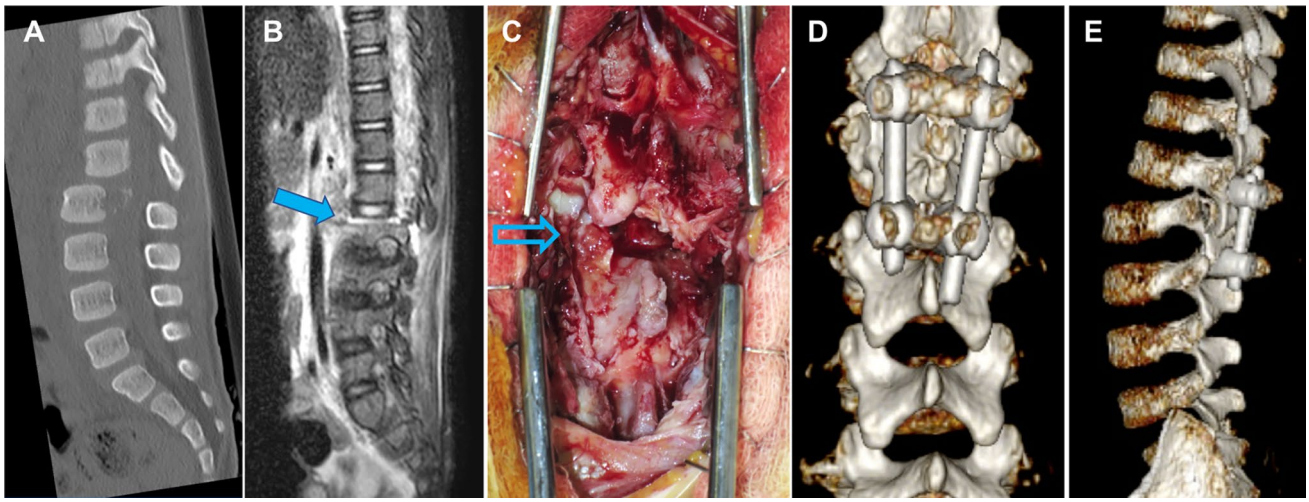

Fig. 2 L1-L2 dislocation with avulsion of the upper discal plate of L2 (**A**, **B**, full arrow), presenting with severe paraplegia; during surgery (**C**, empty arrow); all ligaments were found disrupted; the luxation could be reduced and stabilized with unisegmental fixation with rods and hooks (**D**, **E**); the child then showed rapid recovery of paraplegia

traumatic lesions are rare, child abuse has a disproportionate prevalence, accounting for 19% of spinal injuries under 3 years [14] and 38% of lesions under 2 years [6]; in our experience, child abuse was responsible for 38.7% of spinal traumas in children under 3 years and ranked as the first cause in frequency. The low prevalence of ASL in surgical sources contrasts with radiological studies reporting systematic MRI evaluation of the spine in cases of CA report spinal lesions in more than half of cases 36% [4, 9–11]. Haq et al. stated: "More than 90% of the injury findings are missed on CT or radiography of the spine" [15]. This emphasizes that meticulous study of the spine on MRI in cases of suspected AHI as well as during autopsies should be systematic.

The female predominance in our series was an unexpected finding, all the more since boys are always more represented in AHI; it may suggest either that girls are more sensitive to spinal trauma or conversely that boys are more susceptible to develop intracranial traumatic lesions. This latter hypothesis echoes with the higher incidence of infantile subdural collections in boys, after traumatic as well as non-traumatic events, as reported earlier [16].

Spinal lesions

The predominant level of ASL is debated. Some authors considered that the majority occurred in the upper cervical spine [6, 17], while others reported a prevalence of ASL at the thoraco-lumbar lesion [10]. This discrepancy probably reflects diagnostic and recruitment biases, as mentioned above. In our series, more than half of the patients had thoraco-lumbar or lumbar lesions.

The cervical spine is especially vulnerable because of the mechanical load caused by the oscillating head, as shown by biomechanical studies with dummies [18]. In a historic autopsy series, Hadley et al. found hemorrhagic lesions at the craniocervical level in 5/6 cases; since these cases showed no sign of direct impact, they concluded that these lesions resulted from the "whiplash injury" and contributed to the fatal outcome of SBS [17]. In our series, although many children had cerebral MRI exploring the upper spine, cervical lesions were found in only one case; probably with more systematic holospinal MRI, this figure would increase.

Wedge fracture was the most common finding in our series and suggests an axial compression mechanism [19], in relation with the amplification of movement caused by shaking [20]. These lesions are found at the thoracic and lumbar levels and easily diagnosed on plain X-rays. These have no significant clinical impact and are treated conservatively, but attest the violence of shaking.

Thoraco-lumbar spinal dislocation is considered to be caused by forceful hyperextension and distraction [19]. These lesions can be associated with major, even fatal visceral and vascular lesions [19, 21], replicating the lesions described by Tardieu [1]. Our case illustrated in Fig. 2 shows clearly discal plate avulsion with posterior luxation; such lesions are typical spinal trauma in young children and highly unstable, resulting from a weakened subchondral bone on account of its rich vascular network. The surgical management of unstable thoraco-lumbar lesions in small children is problematic; in our only case, emergency reduction with fixation was performed using laminar hooks and

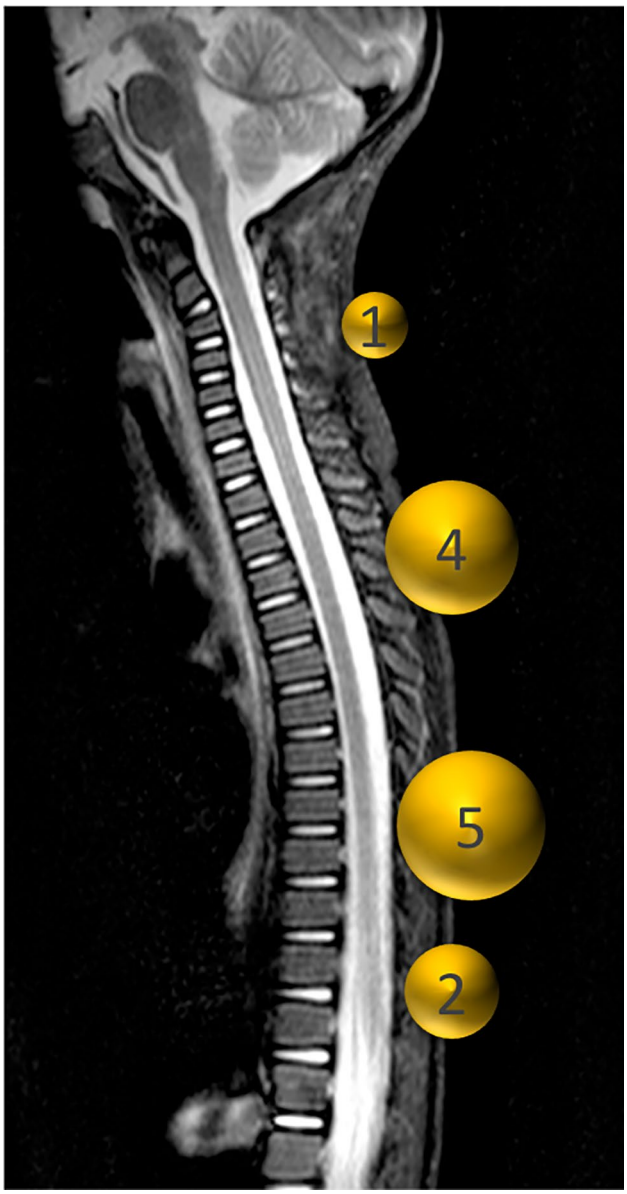

Fig. 3 Distribution of the levels of lesions in the 12 patients. The predominance of abusive spinal lesions at the thoraco-lumbar and lumbar segment is remarkable, because accidental trauma did not occur at these levels in this age group

rods, with satisfactory stabilization and good neurological recovery (Fig. 2).

Neurological consequences

The majority of ASL have no neurological impact and are treated conservatively [6]. Major thoraco-lumbar spinal dislocation causes potentially reversible paraplegia. Severe cervical trauma can cause spinal cord lesions without instability; in this regard, ASL can be a form of SCIWORA (spinal cord injury without radiological anomaly). The resulting tetraplegia causes apnea with anoxic cerebral edema and is one of the factors leading to the infamous big black brain [2, 22]; this outcome explains the prevalence of cervical ASL in autopsy findings [17]. In their Study, Kadom et al. confirmed a clear association between lesions of the cervical spinal cord and extensive cerebral hypoxic lesions [4].

Forensic implications

Not all vertebral fractures in children are traumatic: spinal fractures can complicate many affections, including inborn bone diseases, vitamin D deficiency, steroid-induced osteoporosis, hypopituitarism, kidney transplant, and bone tumors. All these affections are readily diagnosed from their radiological features and from the context. So the main differential diagnosis of ASL is accidental trauma. Accidental spinal lesions are generally caused by high-energy accidents, occurring in older children, are associated with extraspinal traumatic lesions, and involve mostly the cervical level. This exception to the rule "younger means higher" [23] makes traumatic lumbar lesions in small children highly suspicious of abuse.

Whatever the level of ASL, features of AHI are prominent in most cases, and the association of evocative intracranial and spinal traumatic lesions makes the diagnosis of child abuse even more certain. The diagnosis of ASL may be more complicated when ASL are found without cerebral lesions [24]. In our series, only 2 patients had no intracranial lesions; however, their spinal lesions were characteristic of a high-energy trauma, which was incompatible with the mechanism alleged and the child's age. In our opinion, the medicolegal problem is similar in all situations of suspected abuse: when traumatic spinal lesions are not explained by the mechanism alleged, or the mechanism is not compatible with the child's developmental age, ASL should be suspected.

We can discern two entities among ASL. The first one results from shaking, which causes wedge fractures and intraspinal hemorrhage, and may result in severe spinal cord damage without skeletal destruction; in these cases of SBS, the presence of ASL indicates a more violent assault, and the outcome depends mostly on the associated AHI. The second entity, very rare, is a particularly vicious form of BCS, resulting in spinal dislocation; however, with any luck, the brain can be unscathed. In the latter group, our opinion is that the intent to harm and even kill is obvious.

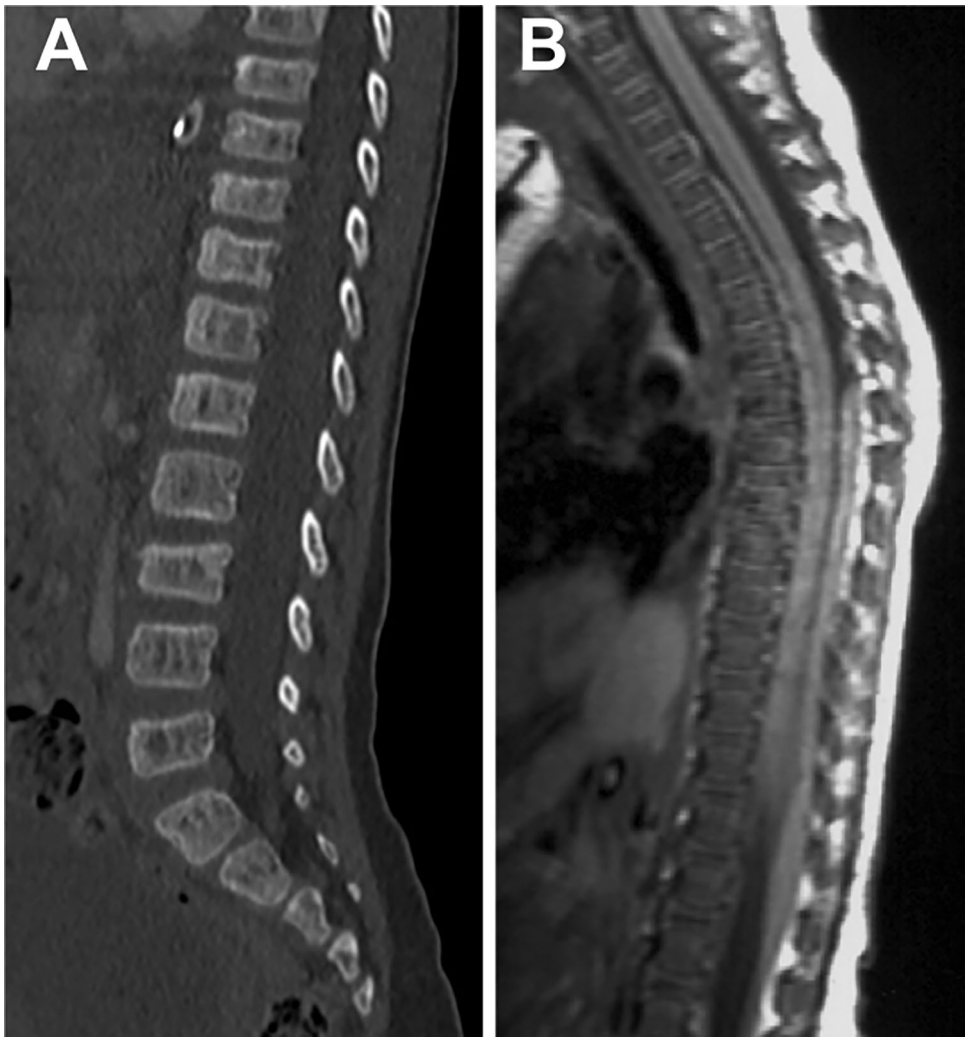

Fig. 4 **A** spinal CT scanner showing wedge fracture of L3. **B** Sagittal T1-weighted MRI showing spinal epidural hematoma centered on the thoracolumbar level

Conclusion

Child abuse is responsible for characteristic spinal traumatic lesions, which are likely underestimated. Shaking represents a specific mechanism of spinal trauma, predominating at the most mobile levels of the spine and causing minor wedge fractures and extramedullary bleeding, but also potentially fatal contusions of the upper cervical spine. The presence of these lesions corroborates the diagnosis of abuse and attests a particularly violent shaking or beating. Spinal cord studies should be systematic in the evaluation of young children suspect of abuse.

Author contribution Dr. Nathalie Noulé collected the legal data. Pr Matthieu Vinchon collected the clinical data and wrote the draft of the paper. Dr. Mélodie-Anne Karnoub and Amélie Toubol revised the manuscript.

Data availability We the authors commit ourselves to provide all data upon request.

Declarations

Ethics approval and consent to participate This study has received ethical clearance IRB approval no. IRB00011687 by the French Collège de Neurochirurgie IRB #1 2022/19; consent to participate is not applicable for a retrospective study.

Consent for publication Consent for publication is given by all authors upon acceptance.

Conflict of interest We the authors declare having no conflict of interest.

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