Pediatr Radiol (2014) 44 (Suppl 4):S621–S631
DOI 10.1007/s00247-014-3170-2

SPECIAL ISSUE: ABUSIVE HEAD TRAUMA

Retroclival collections associated with abusive head trauma in children

V. Michelle Silvera · Amy R. Danehy · Alice W. Newton · Catherine Stamoulis · Chiara Carducci · P. Ellen Grant · Celeste R. Wilson · Paul K. Kleinman

Received: 14 February 2014 / Revised: 7 June 2014 / Accepted: 20 August 2014

Abstract Retroclival collections are rare lesions reported almost exclusively in children and strongly associated with trauma. We examine the incidence and imaging characteristics of retroclival collections in young children with abusive head trauma. We conducted a database search to identify children with abusive head trauma ≤3 years of age with brain imaging performed between 2007 and 2013. Clinical data and brain images of 65 children were analyzed. Retroclival collections were identified in 21 of 65 (32%) children. Ten (48%) were subdural, 3 (14%) epidural, 2 (10%) both, and 6 (28%) indeterminate. Only 8 of 21 retroclival collections were identifiable on CT and most were low or intermediate in attenuation. Eighteen of 21 retroclival collections were identifiable on MRI: 3 followed cerebral spinal fluid in signal intensity and 15 were bloody/proteinaceous. Additionally, 2 retroclival collections demonstrated a fluid-fluid level and 2 enhanced in the 5 children who received contrast material. Sagittal T1-weighted images, sagittal fluid-sensitive sequences, and axial FLAIR (fluid-attenuated inversion recovery) images showed the retroclival collections best. Retroclival collections were significantly correlated with supratentorial and posterior fossa subdural hematomas and were not statistically correlated with skull fracture or parenchymal brain injury. Retroclival collections, previously considered rare lesions strongly associated with accidental injury, were commonly identified in this cohort of children with abusive head trauma, suggesting that retroclival collections are an important component of the imaging spectrum in abusive head trauma. Retroclival collections were better demonstrated on MRI than CT, were commonly identified in conjunction with intracranial subdural hematomas, and were not significantly correlated with the severity of brain injury or with skull fractures.

Keywords Child abuse · Brain · Trauma · Magnetic resonance imaging · Pediatric · Clivus · Computed tomography · Child · Abusive head trauma

V. M. Silvera (✉) · A. R. Danehy · C. Stamoulis · C. Carducci · P. E. Grant · P. K. Kleinman
Department of Radiology, Boston Children's Hospital, Harvard Medical School,
300 Longwood Ave, 02115 Boston, MA, USA
e-mail: michelle.silvera@tch.harvard.edu

A. W. Newton
Child Protection Program, Department of Pediatrics, Massachusetts General Hospital, Harvard Medical School, Boston, MA 02114, USA

C. Stamoulis
Department of Neurology, Boston Children's Hospital, Harvard Medical School, Boston, MA 02115, USA

C. R. Wilson
Division of General Pediatrics, Department of Medicine, Boston Children's Hospital, Harvard Medical School, Boston, MA 02115, USA

Introduction

Abusive head trauma is a major cause of death and disability in infants and young children [1]. In the appropriate clinical context, imaging findings such as multifocal, thin subdural hematomas and parenchymal brain injury may suggest a diagnosis of abusive head trauma.

Retroclival hematomas were first described by Orrison et al. [2] in 1986 and have been subsequently noted in occasional case reports [2–19] and small series [20–23]. Most retroclival epidural and subdural hematomas occur in children, and these collections are almost always reported in the context of accidental trauma, particularly motor vehicle accidents [19, 24–27]. We found no specific reference to retroclival hematomas in the context of abusive head trauma.

Given the strong correlation between retroclival hematomas and accidental pediatric head trauma, we hypothesized that these lesions would be observed in children with abusive head trauma. As such, this study was performed to determine the incidence and imaging characteristics of retroclival collections in a cohort of young children with abusive head trauma.

Materials and methods

This study was approved by the hospital's institutional review board and was compliant with the Health Information Portability and Accountability Act. Informed consent was waived.

Patient cohort and clinical data

In this retrospective study, all children younger than 36 months with abusive head trauma who were treated at a large urban pediatric tertiary-care hospital between 2007 and 2013 and who had a diagnostic-quality head CT or MRI were identified through a search of the hospital's Child Protection Program database and the multidisciplinary child abuse conference list. The age threshold of 36 months was chosen because abusive head trauma is most often noted in infants and toddlers. Abusive head trauma was considered present if the diagnosis was established through a multidisciplinary evaluation, including assessment by a child abuse pediatrician. Factors considered in this assessment included the clinical presentation, imaging findings (including head CT and brain MRI), admission by the perpetrator, and abuse independently witnessed (Table 1). If a case was considered suspicious for abuse but was not confirmed, it was excluded.

Clinical data were abstracted from medical records by a child abuse pediatrician to determine patient demographics and clinical details. Children included in this study had one or more of the following imaging findings: skull fracture, intracranial hemorrhage, and parenchymal brain injury. Children with isolated scalp hematomas or isolated facial bruising were excluded from the study. The time interval between the onset of symptoms and imaging was determined from chart review.

A total of 65 children (29 girls and 36 boys, age range 1–36 months, mean 5.2 months, standard deviation [SD] 5.5 months) met all inclusion criteria for this study.

Table 1 Clinical factors in establishing abuse

	Number who met criteria
Children with abusive head trauma	65
Abuse independently witnessed	4
Abuse acknowledged/confessed	1
Diagnosis established by multidisciplinary assessment child protection team	63
Diagnosis of abuse agreed upon by multispecialty providers[a]	65

[a] Direct care team, child protection MD, hospitalists, neurosurgery, neurology, ophthalmology and radiology, as applicable

Image review

CT and MRI were used to determine the presence or absence of a retroclival collection.

Retroclival epidural collections were defined as fluid collections along the clivus deep to the tectorial membrane. Retroclival subdural collections were defined as fluid collections superficial to the tectorial membrane and deep to the arachnoid membrane (Fig. 1). Retroclival collections were defined as indeterminate if the collection was identified on CT only (and no MRI was performed or if the retroclival collection had resolved by the time MRI was performed) or if the tectorial membrane could not be definitively identified on MRI. If a retroclival collection was identified on either modality, it was deemed present.

CT imaging was performed on a LightSpeed 16 Slice CT or Optima CT660 (General Electric Healthcare, Milwaukee, WI) or a SOMATOM Sensation 64 (Siemens, Erlangen, Germany) with the use of non-helical 5-mm contiguous axial images. In the latter part of the study period, head CTs were routinely reconstructed into 0.625-mm axial datasets and reformatted into 3-mm-thick sagittal and coronal image sets using a standard algorithm.

MR imaging was performed on a 3T Magnetom Skyra or Trio scanner (Siemens, Erlangen, Germany) or a 1.5T Signa Excite (General Electric Healthcare, Milwaukee, WI). Standard pulse sequences acquired on the 3T MRI system included sagittal 3D volumetric T1-weighted spoiled gradient echo images (0.9-mm section thickness) reformatted into axial and coronal planes (0.9-mm section thickness, 0-mm gap), axial and coronal fast spin echo (FSE) T2-weighted images (2.5-mm section thickness, 0-mm gap), axial T2-weighted fluid-attenuated inversion recovery (FLAIR) images (4-mm section thickness, 0-mm gap), and axial diffusion tensor imaging (DTI) images (2-mm section thickness, 0-mm gap). Imaging on the 1.5 T MRI system consisted of sagittal T1-weighted spin echo

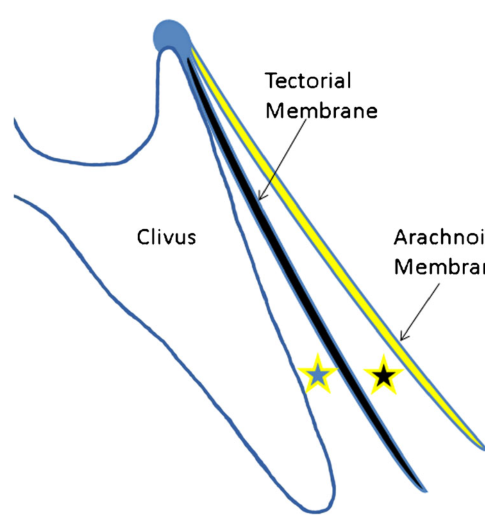

Fig. 1 Illustration of a retroclival collection in the sagittal plane. The tectorial membrane is *black*, the arachnoid membrane *yellow*; the *blue* star defines the epidural space, the *black* star the subdural space

images (4-mm section thickness, 0-mm gap), axial and coronal FSE T2-weighted images (4-mm section thickness, 0-mm gap), axial T2-weighted FLAIR images (5-mm section thickness, 1.0-mm gap), and DTI images (5-mm section thickness, 0-mm gap). Variably obtained sequences included axial susceptibility-weighted images (SWI) (1.25-mm thick section, 0-mm gap), axial steady-state gradient echo images (4-mm section thickness, 0-mm gap), axial or sagittal T2-weighted 3D variable-flip-angle FSE images (0.5-mm section) reformatted in 0.5-mm-thick sections in orthogonal planes, axial or sagittal fast imaging employing steady-state acquisition images (0.8-mm section thickness) reformatted in 0.8-mm-thick sections in orthogonal planes, sagittal FSE inversion recovery images (3-mm section thickness, 0-mm gap) and axial T1-weighted spin echo post-gadolinium (5-mm section thickness, 0-mm gap) or sagittal 3D volumetric T1-weighted spoiled gradient echo post-gadolinium images (0.9-mm section thickness) reformatted into axial and coronal planes.

Variable sequences were available in individual patients because imaging protocols for abusive head trauma evolved over time. In particular, fluid-sensitive sequences, defined as T2-weighted 3D variable-flip-angle FSE, fast imaging employing steady-state acquisition or FSE inversion recovery images, were more commonly added to the imaging protocol in the latter part of the study period. Moreover, abuse was not always the initial clinical consideration at the time of first imaging, e.g., a child may have been imaged for new-onset seizures before abuse was contemplated. Findings were therefore expressed as percentages of findings positively identified relative to the total number of patients in whom a specific finding could be assessed based on the available imaging sequences. MR imaging sequences available for each patient with a retroclival collection are listed in Table 2.

All imaging was independently analyzed and classified by two board-certified fellowship-trained pediatric neuroradiologists with 15 and 8 years of experience. Interobserver differences were resolved and classified by consensus following agreement between the readers.

Characteristics of retroclival collections such as location, attenuation, signal intensity, enhancement, and the presence of

Table 2 MRI sequences performed in the children with a retroclival collection and abusive head trauma

Case	1.5 T	3.0 T	Sag T1	Sag or axial T1 post contrast	Axial T2	Axial FLAIR	Axial GRE/ SWI	Axial DTI	Sag FSEIR	Sag or axial T2-weighted 3D variable-flip-angle FSE	Sag or axial fast imaging employing steady-state acquisition
1	+	-	+	+	+	+	+	+	+	-	-
2	-	+	+	-	+	-	+	+	-	-	-
3	+	-	+	+	+	-	+	+	-	-	-
4	+	-	+	+	+	-	+	+	-	-	-
5	+	-	+	-	+	-	-	+	+	-	-
6	+	-	+	+	+	+	+	-	-	-	-
7[a]	-	-	-	-	-	-	-	-	-	-	-
8[b]	-	+	+	-	+	-	-	+	-	-	-
9	+	-	+	-	+	+	+	+	+	-	-
10	+	-	+	+	+	+	+	+	-	-	-
11	+	-	+	-	+	+	+	+	-	-	-
12	-	+	+	-	+	+	+	+	+	+	-
13	+	-	+	-	-	-	-	-	-	-	-
14	-	+	+	-	+	+	+	+	-	-	-
15	+		+	-	+	-	+	+	+	-	-
16	-	+	+	-	+	-	+	+	+	+	-
17	+	-	+	-	+	+	+	+	-	-	-
18	+	-	+	-	+	+	+	+	+		+
19	-	+	+	-	+	+	+	+	+	+	
20[a]	-	-	-	-	-	-	-	-	-	-	-
21	-	+	+	-	+	+	+	+	+	-	+

[a] No MRI performed

[b] RCC Retroclival collection

DTI diffusion tensor imaging, *FLAIR* Fluid-attenuated inversion recovery, *FSE* fast spin echo in footer, *FSEIR* fast spin echo inversion recovery, *GRE* gradient echo, *Sag* sagittal, *SWI* susceptibility-weighted imaging fluid-fluid levels were examined. If more than one head CT or MRI was performed during the same hospital admission, the first head CT and the first MRI were used to determine the attenuation and signal characteristics of the retroclival collection. Retroclival collections were categorized as subdural, epidural, both subdural and epidural, or indeterminate. Because axial FLAIR images can show flow-related artifact in the retroclival region, the sequence was not used to determine the presence or absence of a retroclival collection.

Additional neuroimaging findings including skull fracture, subdural hematoma and parenchymal brain injury were identified. Supratentorial subdural hematomas were defined as one or more subdural hematoma in the supratentorial space, unilateral, bilateral, or interhemispheric in location. Posterior fossa subdural hematomas were defined as one or more subdural hematoma along the occipital squama. Parenchymal brain injury was defined as any area of parenchymal tissue alteration that was bright on T2-weighted MR images and correspondingly bright on the diffusion trace-weighted map and dark on the apparent diffusion coefficient (ADC) map. Images were not separately analyzed for parenchymal edema without restricted diffusion or bridging vein thrombosis. Details of retinal hemorrhages and skeletal fractures were abstracted from the medical record.

Statistical methods

Interobserver agreement was assessed using Cohen's kappa statistic. Correlations between a retroclival collection and either skull fracture, supra- or infratentorial parenchymal injury; and supra- or infratentorial subdural hematomas were assessed using simple contingency tables and the Fisher exact test or chi-squared test.

Results

Interobserver agreement

There was excellent interobserver agreement (Cohen's kappa $\kappa=0.96$, 95% confidence interval [0.89,1])) for identifying the presence of a retroclival collection in this cohort of children

Table 3 Demographics and imaging characteristics of retroclival collections (RCC)

Case	Age (mos)	Gen-der	RCC Location	CT available	Day of CT since symptom onset	CT sagittal reformatted images available	CT density	MRI available	Day of MRI since symptom onset	RCC signal intensity	RCC enhancing	RCC fluid-fluid level
1	2	F	EDC	Yes	Day 1	No	Not seen	Yes	Day 2	[a]	No	No
2	3	M	SDC	Yes	Day 1	Yes	Not seen	Yes	Day 1	[a]	No Gad	No
3	1	F	Both[b]	Yes	Day 1	Yes	Not seen	Yes	Day 2	[a]	Yes	Yes
4	3	M	SDC	Yes	Day 1	No	Not seen	Yes	Day 5	CSF	No	No
5	1	M	SDC	Yes	Day 1	Yes	Not seen	Yes	Day 3	CSF	No Gad	No
6	5	F	ID	Yes	Day 1	No	Not seen	Yes	Day 2	[a]	No	No
7	2	M	ID	Yes	Day 1	Yes	Intermed	No	No MRI	NA	NA	No
8	16	F	ID	Yes	Day 1	Yes	Intermed	Yes	Day 1	Resolved	No Gad	No
9	36	M	SDC	Yes	Day 1	Yes	Intermed	Yes	Day 1	[a]	No Gad	No
10	30	M	SDC	Yes	Day 1	No	Not seen	Yes	Day 1	[a]	Yes	No
11	7	F	SDC	Yes	Day 2	Yes	Intermed	Yes	Day 4	[a]	No Gad	No
12	7	F	SDC	Yes	Day 2	Yes	Not seen	Yes	Day 4	[a]	No Gad	No
13	8	M	ID	Yes	Day 4	Yes	Not seen	Yes	Day 9	[a]	No Gad	No
14	3	M	SDC	Yes	Day 2	Yes	Not seen	Yes	Day 3	[a]	No Gad	No
15	1	M	EDC	Yes	Day 1	No	Not seen	Yes	Day 2	[a]	No Gad	No
16	4	F	SDC	Yes	Day 1	Yes	Low	Yes	Day 2	[a]	No Gad	No
17	13	M	EDC	No	No CT	NA	NA	Yes	Day 16	[a]	No Gad	No
18	1	M	ID	Yes	Day 1	No	Not seen	Yes	Day 3	[a]	No Gad	Yes
19	4	M	SDC	Yes	Day 1	Yes	Intermed	Yes	Day 2	CSF	No Gad	No
20	6	M	ID	Yes	Day 1	Yes	High	No	No MRI	NA	NA	No
21	30	F	Both[b]	Yes	Day 1	No	Intermed	Yes	Day 2	[a]	No Gad	No

[a] Intermediate or dark signal on T2-weighted images, or intermediate or bright signal on T1-weighted images, or mixed signal intensity on T1- or T2-weighted images, or intermediate signal on fluid-attenuated inversion recovery images

[b] Both epidural and subdural collections present

CSF cerebrospinal fluid, *EDC* epidural collection, *F* female, *Gad* gadolinium, *ID* indeterminate, *M* male, *mos* months, *NA* not applicable, *SDC* subdural collection

Table 4 Additional findings in children with retroclival collections (RCC) and abusive head trauma (AHT)

Case	Posterior fossa SDH	Posterior fossa cerebellar injury	Supratentorial findings and skull fracture (SFX)	Retinal hemorrhage	Skeletal survey
1	SDH	Absent	SDH, PI	Yes, B	Ribs, CML humerus, CML tibia, femur
2	SDH	Present	SDH, PI, IVH, SAH	Yes, B	Negative
3	SDH	Absent	SDH, PI, SFX	No	Negative
4	SDH	Absent	SDH, PI, SFX	No	Ribs
5	SDH	Absent	SDH, PI	Yes, B	Ribs, radius, CML femur, CML tibia, clavicle
6	SDH	Absent	SDH	Yes, B	Negative
7	No	NA[a]	SDH, SFX	N.E.	Negative
8	SDH	Present	SDH, PI	Yes, B	Negative
9	SDH	Absent	SDH, PI	Yes, B	Radius
10	SDH	Absent	SDH, PI	Yes, B	Fibula, multiple thoracic vertebral bodies
11	SDH	Absent	SDH, PI	Yes, B	Negative
12	SDH	Absent	SDH, SFX	No	Negative
13	SDH	Absent	SDH	Yes, B	Negative
14	SDH	Absent	SDH	Yes, B	Negative
15	SDH	Absent	SDH	Yes, U	Clavicle, CML femur, CML tibia, CML fibula
16	SDH	Absent	SDH	Yes, B	Negative
17	SDH	Absent	SDH, PI	Yes, B	Negative
18	SDH	Absent	SDH, PI	No	Ribs, CML femur, CML tibia
19	SDH	Present	SDH, PI	Yes, B	CML tibia
20	SDH	NA[a]	SDH, PI	Yes, B	Negative
21	SDH	Absent	SDH	Yes, U	Negative

[a] no MRI performed; *B*, Bilateral; *CML*, classic metaphyseal lesion; *IVH*, intraventricular hemorrhage; *NA*, not applicable; no *MRI*, available; *N.E.*, not examined; *PI*, parenchymal injury; *SAH*, subarachnoid hemorrhage; *SDH*, subdural hematoma; *U* unilateral

with abusive head trauma, with one discrepant read, which was resolved by consensus.

Imaging findings

Retroclival collections were identified in 21/65 (32%) children (age range 1–36 months, mean 8.7 months, SD 10.5 months). Patient demographics, clinical determination of retinal hemorrhage, imaging and associated findings in children with abusive head trauma and retroclival collections are summarized in Tables 3 and 4. Of the 65 children in this cohort, 62 children (95%) had head CTs; 43 of those 62 (69%) children had sagittal reformatted images and 19 (31%) did not. Almost all of the 65 patients (58 children, 89%) underwent MRI imaging of the brain.

Retroclival collections were identified in 8/62 (13%) children on head CT and 18/57 (32%) by MRI. In 5 children a retroclival collection was identified on both modalities (4 subdural collections and 1 epidural collection with a subdural collection). Of the 18 children with retroclival collections identified on MRI, 12 (67%) (2 epidural collections, 6 subdural collections, 1 subdural with epidural collection, 3 indeterminate collections) could not be identified on the preceding head CT; 5 were seen on the prior head CT; and 1 child (epidural collection) had a brain MRI examination but no head CT. Seven of the 8 (88%) children in whom a retroclival collection was detected on head CT had sagittal reformatted images available for interpretation. In three children, retroclival collections were identified only by head CT; in two of these, CT was the only imaging modality utilized and in one child a retroclival collection initially present on the CT performed at 1.5 h post injury was resolved on the CT at 6 h post injury (Fig. 2) and the MRI performed 7 h post injury confirmed resolution.

The location, CT attenuation and MRI signal characteristics of the retroclival collections are listed in Table 3. Of the 21 retroclival collections, subdural collections (10 of 21; 48%) (Fig. 3) were more commonly observed than epidural collections (3 of 21; 14%), and combined epidural and subdural collections (2 of 21; 10%) (Fig. 4) were least common. Six collections (6 of 21; 28%) could not be categorized and were classified as indeterminate for the following reasons: two children did not have an MRI following their head CT and thus by definition were indeterminate in location; in one child the retroclival collection had resolved by the time the MRI was performed and therefore only a head CT was available for classification; in two cases the collections were well seen, but the lack of a sagittal fluid-sensitive sequence precluded accurate localization of the collections (Fig. 5); and in one case the

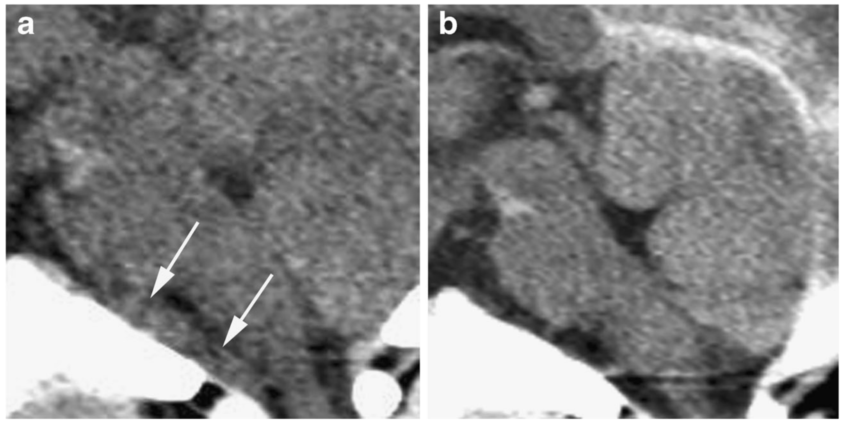

Fig. 2 CT in a 16-month-old girl with a retroclival collection (case 8, indeterminate). **a** Sagittal reformatted CT image 1.5 h post symptom onset shows an intermediate-density retroclival collection (*arrows*). **b** Sagittal reformatted CT image 6 h post symptom onset shows resolution of the retroclival collection. Resolution was confirmed on a brain MRI performed 7 h post symptom onset (not shown)

Fig. 3 CT and MRI in a 7-month-old girl with a retroclival subdural collection (case 11). **a** Sagittal reformatted CT image performed 2 days post symptom onset shows the subdural collection (*long arrows*) as intermediate in density. Note the retroclival collection is superficial to the tectorial membrane (*short arrow*). **b** Sagittal reformatted CT image performed 3 days post symptom onset shows that the collection is increased in size and density. **c** Sagittal T1-weighted spin echo MR image 4 days post symptom onset shows the collection (*white arrow*) as bright in signal and superficial to the tectorial membrane (*black arrow*)

membrane overlying the collection was well seen and likely represented the arachnoid membrane, but the angle of the membrane relative to the clivus was considered atypical (case 18).

The earliest point at which a retroclival collection was identified on imaging was 1.5 h post symptom onset. The earliest point at which a retroclival collection resolved was 6 h post symptom onset. The latest point at which a retroclival collection

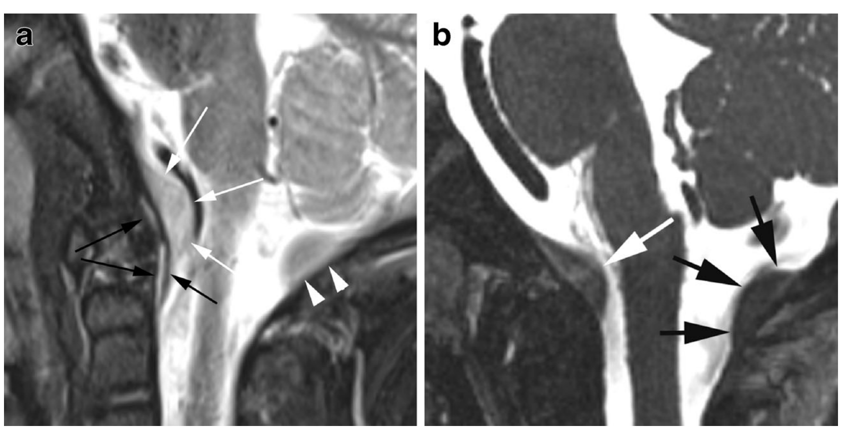

Fig. 4 MRI in a 30-month-old girl with a combined retroclival epidural and subdural collection (case 21). **a** Sagittal fast spin echo inversion recovery image shows a small epidural collection (*long black arrows*) deep to the tectorial membrane (*short black arrow*). A subdural collection (*white arrows*) overlies the tectorial membrane. Note the subdural hematoma along the occipital squama (*arrowheads*). **b** Sagittal fast imaging employing steady-state acquisition sequence shows the subdural collections along the clivus (*white arrow*) and occipital squama (*black arrows*)

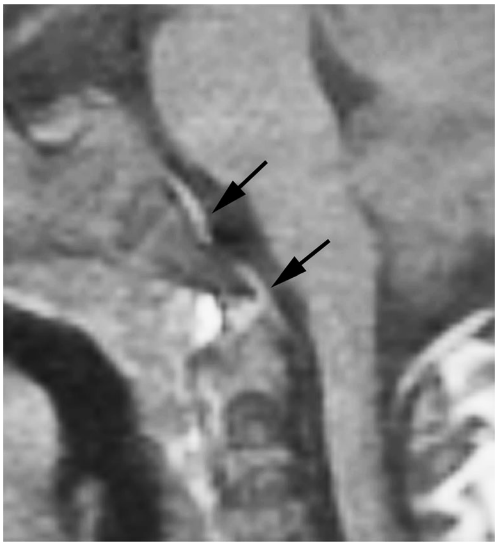

Fig. 5 MRI in an 8-month-old boy with a retroclival collection (case 13, indeterminate). Sagittal T1-weighted image shows a hyperintense retroclival collection. The tectorial membrane is not clearly visualized

was identified on imaging during the same hospital admission was 19 days post symptom onset. Ten children with retroclival collections identified on MRI underwent a second MRI examination during the same hospital admission and of these 10 children, retroclival collections could still be identified in 9 (range 2–19 days, mean 10.8 days).

Of children with a retroclival collection, 19 underwent brain MRI, on which 18 retroclival collections were identified. The sagittal sequences employed in the MRI examinations that detected retroclival collections were as follows: 18 children were imaged with a sagittal T1-weighted sequence and 9 children with sagittal fluid-sensitive sequences. Retroclival collections were identified on sagittal T1-weighted images in 16/18 (89%), and on sagittal fluid-sensitive sequences in 9/9 (100%). In regard to axial brain imaging, of the 18 children with a retroclival collection identified by MRI, 18 had T2-weighted sequences, 16 had susceptibility sequences (SWI or steady-state gradient echo images), and 11 had FLAIR images (axial FLAIR imaging is not typically included in our infant brain imaging protocol and was therefore not consistently available for interpretation). Retroclival collections were visualized on axial T2-weighted images in 7/18 (39%), axial susceptibility images in 4/16 (25%) and axial FLAIR images in 9/11 (82%). Five children had gadolinium-enhanced MRIs and in two cases the retroclival collections enhanced (Fig. 6). A fluid-fluid level was observed in 2 of 18 children with RCCs (Fig. 7).

Other posterior fossa and impact injuries

Subdural hematomas were concurrently noted within the posterior fossa along the occipital squama by CT or MRI in 20/21 (95%) children with retroclival collections (Figs. 4 and 6).

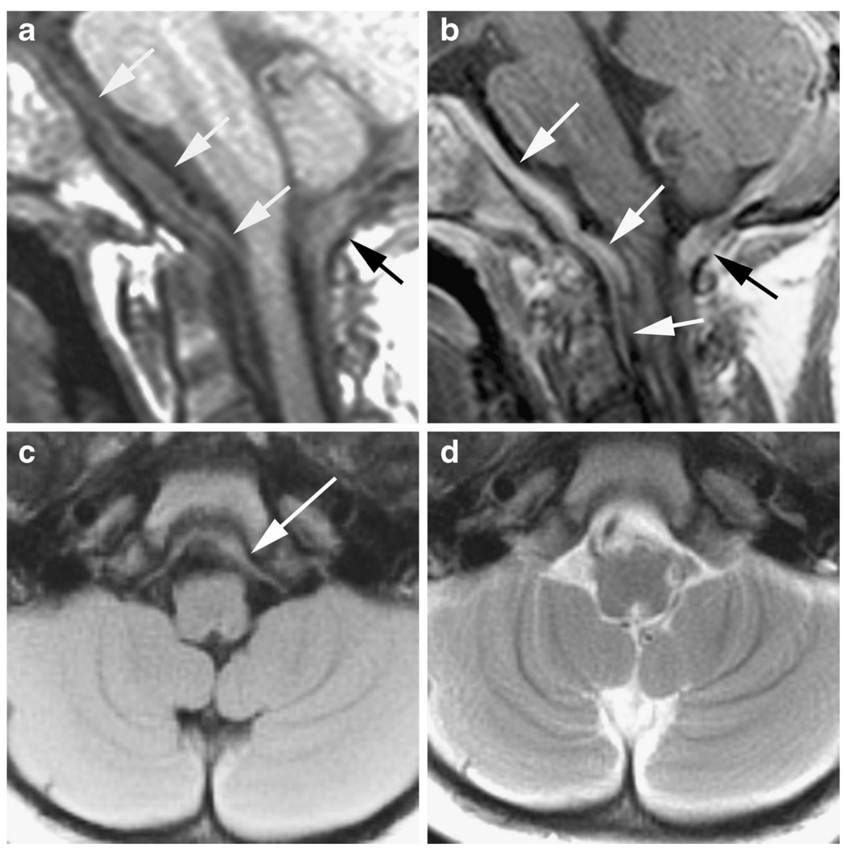

Fig. 6 MRI in a 30-month-old boy with an enhancing retroclival subdural collection (case 10). **a** The sagittal T1-weighted image shows a retroclival subdural collection (*white arrows*) and an occipital squama subdural hematoma (*black arrow*). **b** Sagittal T1-weighted post-contrast image shows enhancement of the retroclival subdural collection (*white arrows*) and the occipital squamal subdural hematoma (*black arrow*). **c** Axial FLAIR image shows the retroclival collection along the clivus (*arrow*), whereas the axial T2-weighted image (**d**) does not. *FLAIR* fluid-attenuated inversion recovery

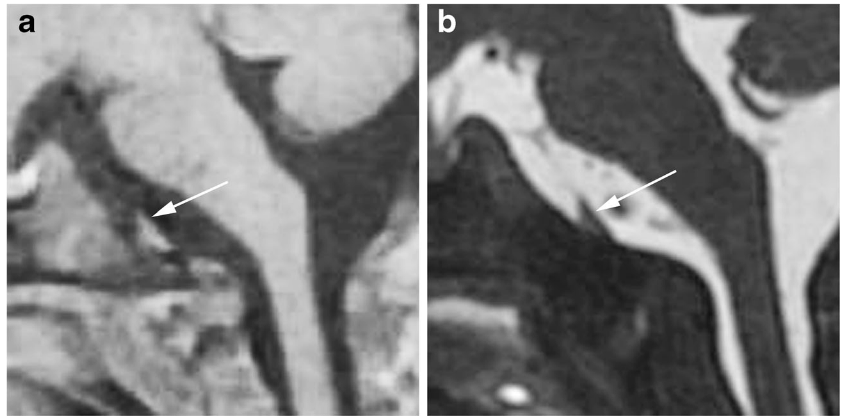

Fig. 7 MRI in a 1-month-old boy with a retroclival collection (case 18, indeterminate). **a** Sagittal T1-weighted and (**b**) sagittal fast imaging employing steady-state acquisition images show a retroclival collection with a fluid-fluid level (*arrows*) representing the interface between sediment and supernatant

Imaging resolution did not allow for assessment for continuity between occipital squama subdural hematomas and retroclival collections. In 3/21 (14%) children with retroclival collections, parenchymal injury of the cerebellum was also present. Of those children without a retroclival collection (n=44), 28/44 (64%) had subdural hematomas along the occipital squama and 8/44 (18%) had parenchymal injury of the cerebellum. Skull fractures were present in 4/21 children (19%) with a retroclival collection and in 15/44 (34%) children without a retroclival collection. There was a statistically significant correlation between retroclival collections and occipital squama subdural hematomas (P=0.0066); there was no statistically significant correlation between retroclival collections and skull fracture (P=0.21) or cerebellar parenchymal injury (P=0.69). Finally, no child was found to have a focal contusion of the brainstem or cerebellum, brainstem compression, epidural hematoma along the occipital squama, or clival fracture. In addition, no child had evidence of a ruptured tectorial membrane as has been described in children with retroclival epidural hematomas occurring with accidental trauma [28].

Additional findings

The additional neuroimaging, clinical and skeletal survey findings are detailed in Table 4. Thirteen children with a retroclival collection had parenchymal injury of the supratentorial brain parenchyma, and all (n=21) had supratentorial subdural hematomas. There was a statistically significant correlation between retroclival collections and supratentorial subdural hematomas (P=0.018) but no significant correlation with parenchymal injury of the cerebral hemispheres (P=0.16). No retroclival collection demonstrated enough mass effect in the posterior fossa to cause obstructive hydrocephalus from localized brainstem compression. In one child, a retroclival collection was contiguous with a subdural collection in the cervical and thoracic spinal canal (case 12, Fig. 8). No child underwent surgical evacuation of a retroclival collection.

Discussion

Retroclival collections were relatively common (32%) in our cohort of young children with abusive head trauma. This finding contrasts with the general consensus that these collections are rare [4, 6, 10, 11, 22]. Retroclival collections were best visualized on CT in children with sagittal reformatted images and on MRI in the sagittal plane on T1-weighted, T2-weighted 3D variable-flip-angle FSE, fast imaging employing steady-state acquisition, and FSE inversion recovery images, and in the axial plane on FLAIR images.

A retroclival collection can be subdural or epidural in location and occasionally a combination of both is identified. To ascertain the location of a retroclival collection, the tectorial membrane, a thin sheet-like structure that is continuous

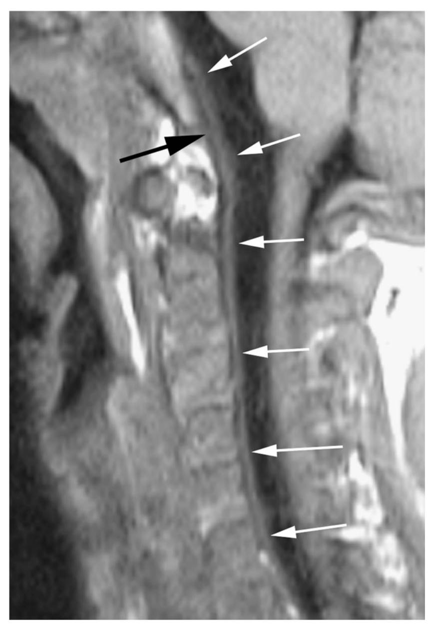

Fig. 8 MRI in a 7-month-old girl with a retroclival subdural collection extending into the spinal canal (case 12). Sagittal T1-weighted image shows a thin but extensive subdural collection extending from the mid clivus into the spinal canal (*white arrows*). The tectorial membrane is well seen (*black arrow*)

with the intracranial dura mater and extends from the mid-clivus to the base of C2, has to be identified [29]. Fluid collections deep to the tectorial membrane are epidural in location and those superficial to the tectorial membrane are subdural [30]. In this study, the most common type of retroclival collection was located in the subdural compartment (48%). Less common were retroclival epidural collections (14%) or combined retroclival epidural and subdural collections (10%). Approximately one-third (28%) of collections were categorized as indeterminate for the following reasons: the retroclival collection was identified on CT only and no brain MRI was performed; the retroclival collection resolved (on CT) prior to the MRI being performed; and MRI detail/available sequences did not permit reliable identification of the tectorial membrane and therefore limited categorization of the retroclival collection.

Several mechanisms have been proposed for the formation of clival epidural hematomas which include stripping of the tectorial membrane from the surface of the clivus from hyperextension injury resulting in traumatic injury to the tectorial membrane and bleeding from the injured dura; traumatic disruption of the local vasculature such as the meninohypophyseal trunk or basilar plexus; and clival fracture or diastasis of the spheno-occipital synchondrosis with dural bleeding [4, 5, 8]. Clival subdural hematomas are rarely reported and the source of bleeding is not clearly understood because there are few vessels in the clival subdural space [30, 31]. We hypothesize that fluid within the subdural space can accumulate secondary to (1) dural injury, resulting in bleeding; (2) a traumatic arachnoid tear allowing cerebrospinal fluid to enter the subdural space, which would explain the three CSF-intensity subdural collections seen in this cohort, and (3) redistribution of subdural fluid/blood from subdural hematomas located along the occipital squama or middle cranial fossa.

The clinical presentation of children with retroclival collections varies. Children with retroclival epidural hematomas occurring in the setting of accidental trauma often present with neurological deficits ranging from lower cranial nerve paresis to tetraplegia and loss of spontaneous respiration [21–23, 28]. Children with retroclival subdural hematomas arising from accidental injury may present with hemiparesis and respiratory arrest but children can also be asymptomatic [27, 30, 32]. Neurological abnormalities observed in accidentally injured children with retroclival collections may be related to localized injury to posterior fossa contents with stretching, direct compression or contusion of nerves and brain tissue. In addition, deficits may reflect broader injury to the central nervous system [33]. Correlating neurological deficits in abused infants to retroclival epidural or subdural collections can be especially challenging, particularly when there is polytrauma with additional intracranial injuries in a sedated/intubated patient. In this study, correlation of retroclival collections with neurological abnormalities was not possible based on a lack of detailed neurological findings documented in the medical records.

The imaging appearances of retroclival subdural and epidural collections differed in this study. Retroclival subdural collections were either low or intermediate in attenuation on the first CT examination. This resulted in a subtle appearance of these collections in the axial plane, which was further compounded by volume averaging with the clivus and beam hardening artifact arising from the calvarium. Sagittal reformatted images were helpful in identifying some but not all retroclival subdural collections. Interestingly, no retroclival subdural collection was of high or mixed attenuation on the first CT examination, an appearance that is considered common for supratentorial subdural hematomas in children with abusive head trauma [34–36].

On MRI, one-third of retroclival subdural collections approximated cerebral spinal fluid in signal intensity. These collections represented either subdural hygromas, possibly related to an arachnoid tear with leakage of CSF into the subdural space [34, 36, 37], hematohygromas or chronic subdural hematomas. The remaining two-thirds of retroclival subdural collections followed signal intensities consistent with hemorrhagic/proteinaceous fluid content.

By contrast, retroclival epidural collections followed signal intensities consistent with bloody/proteinaceous fluid. Furthermore, retroclival epidural hematomas were not easily detected on head CT, and all isolated retroclival epidural collections were identified on MRI only. This is of potential clinical significance because retroclival epidural hematomas seen in accidentally injured children are usually associated with craniocervical junction injuries [4, 21, 28].

We detected more than twice as many retroclival collections with MRI than with CT, which suggests superior sensitivity of MRI compared to CT. Sagittal T1-weighted images, sagittal fluid-sensitive and axial FLAIR images showed the collections best, demonstrating the collections in 89%, 100% and 82% of cases, respectively. Axial T2-weighted MR images and susceptibility sequences did not show the collections well, positive in only 37% and 25% of cases, respectively. In some imaging centers, sagittal fluid-sensitive sequences are not incorporated into pediatric brain trauma protocols, and axial FLAIR sequences are omitted in infants. Thus, supplementation of brain imaging with these potentially helpful sequences should be considered when assessing children for abusive head trauma.

Several interesting imaging features of retroclival collections were observed in this study. Two children with retroclival collections demonstrated fluid-fluid levels within the collection, representing separation of blood components into sediment and supernatant. Additionally, 2 of 5 children who received gadolinium on MRI showed enhancement of the retroclival collection. The mechanism of enhancement of subdural collections is not known. Hypotheses put forward include passive diffusion of contrast agent into the subdural space similar to accumulation of contrast agent in pineal cysts and contrast leakage from neovasculature in children with preexistent subdural collections [38]. One child demonstrated continuity of a retroclival subdural collection with a cervical and thoracic subdural collection. This observation suggests that it is possible that posterior fossa subdural hematomas resolve, at least in part, by redistribution of blood from the posterior fossa into the spinal subdural space [39]. This mechanism would explain the rapid resolution of the retroclival collection seen in case 8, which resolved within 6 h of injury. Rapid resolution of a retroclival subdural hematoma into the spinal compartment has also been reported in a child with accidental trauma [19].

In our cohort, some retroclival collections resolved quickly, while others remained evident days after the initial symptom onset. About half were visible on MRI at an average of 10 days after symptom onset and one was still visible on day 19. Therefore, even if a brain MRI is delayed for several days after admission, a retroclival collection may still be detectable.

In addition to retroclival collections, other posterior fossa abnormalities were identified, such as subdural hematomas along the occipital squama, a common finding in children with abusive head trauma, as well as cerebellar parenchymal injury, which is less commonly observed in these children and associated with poor neurodevelopmental outcomes [40]. Retroclival collections were significantly correlated with posterior fossa subdural hematomas but not with parenchymal injury of the cerebellum.

No child in this study had a retroclival collection large enough to cause brainstem compression or hydrocephalus from localized brainstem compression. Nor did any child have evidence of a brainstem or cerebellar contusion or a clival fracture, all findings previously reported in children with retroclival hematomas occurring with accidental trauma [2, 7, 8, 10].

The spectrum of tectorial membrane abnormalities described in accidentally injured children ranges from bowing/elevation of the tectorial membrane to partial and complete tectorial membrane tears with frank disruption. We did not identify any child with a partial or complete tear of the tectorial membrane, findings seen at the most severe end of the injury spectrum in children with accidental trauma [28, 41]. Furthermore, all children with retroclival collections in this cohort were managed expectantly, as opposed to children with accidental trauma who are occasionally treated surgically [7, 9, 11, 20].

In regard to supratentorial head injury, retroclival collections were significantly correlated with supratentorial subdural hematomas but not with parenchymal brain injury or skull fracture. This suggests that in cases of abusive head trauma, retroclival collections are not necessarily associated with more severe brain injury patterns or injuries that involve blunt force trauma.

This study is limited by its retrospective nature and modest cohort size. Results need to be validated in a larger prospective study. Also, as with most studies of abusive head trauma, we cannot be certain of the exact timing of injury in our cases and can only draw inferences based on when patients presented for care and histories provided by caretakers regarding the onset of symptoms. Imaging findings on head CT and MRI were taken into consideration in the clinical multidisciplinary assessment of the children in this cohort. Although the presence of an intracranial subdural hematoma or a retroclival collection on imaging did not constitute an inclusion criterion for diagnosing abuse, knowledge of the presence of these findings in the clinical assessment represented a confounding factor. Nevertheless, these findings were but two of many additional data points considered in the final determination of abusive injury. CT and MRI were not both available for all patients with identified retroclival collections, and thus in a few cases modalities with differential sensitivities for retroclival collections were used. In addition, children were admitted to the hospital on an emergent basis and the institution is a tertiary care center. Therefore, the cohort may have been skewed toward the more severe end of the spectrum of abusive head trauma. Finally, lack of detailed neurological assessments available in the medical charts limited our ability to correlate retroclival collections to specific neurological deficits.

Conclusion

Our study shows that retroclival collections are relatively common in children with abusive head trauma and suggests that these collections are an important component of the abusive head trauma imaging spectrum. Retroclival collections can be subtle in appearance, are better demonstrated on MRI than on CT, and can be overlooked if care is not taken with image acquisition and interpretation. Retroclival collections were commonly identified in conjunction with multifocal subdural hematomas, which are considered hallmark findings in abusive head trauma, but were not significantly correlated with brain parenchymal injury or skull fracture.

Conflicts of interest None.

References

1. Piteau SJ, Ward MG, Barrowman NJ et al (2012) Clinical and radiographic characteristics associated with abusive and nonabusive head trauma: a systematic review. Pediatrics 130:315–323
2. Orrison WW, Rogde S, Kinard RE et al (1986) Clivus epidural hematoma: a case report. Neurosurgery 18:194–196
3. Agrawal D, Cochrane DD (2006) Traumatic retroclival epidural hematoma — a pediatric entity? Childs Nerv Syst 22:670–673

4. Guillaume D, Menezes AH (2006) Retroclival hematoma in the pediatric population. Report of two cases and review of the literature. J Neurosurg 105:321–325
5. Kurosu A, Amano K, Kubo O et al (1990) Clivus epidural hematoma. Case report. J Neurosurg 72:660–662
6. Kwon TH, Joy H, Park YK et al (2008) Traumatic retroclival epidural hematoma in a child: case report. Neurol Med Chir 48:347–350
7. Marks SM, Paramaraswaren RN, Johnston RA (1997) Transoral evacuation of a clivus extradural haematoma with good recovery: a case report. Br J Neurosurg 11:245–247
8. Mizushima H, Kobayashi N, Sawabe Y et al (1998) Epidural hematoma of the clivus. Case report. J Neurosurg 88:590–593
9. Papadopoulos SM, Dickman CA, Sonntag VK et al (1991) Traumatic atlantooccipital dislocation with survival. Neurosurgery 28:574–579
10. Suliman HM, Merx HL, Wesseling P et al (2001) Retroclival extradural hematoma is a magnetic resonance imaging diagnosis. J Neurotrauma 18:1289–1293
11. Yang BP (2003) Traumatic retroclival epidural hematoma in a child. Pediatr Neurosurg 39:339–340
12. Castillo C, Lambre H, Meli F (1994) Acute extra-axial hematoma post-traumatic of the clivus. Medicina (B Aires) 54:150–152
13. Muller JU, Piek J, Kallwellis G et al (1998) Prepontine epidural hemorrhage. Zentralbl Neurochir 59:185–188
14. Paterakis KN, Karantanas AH, Hadjigeorgiou GM et al (2005) Retroclival epidural hematoma secondary to a longitudinal clivus fracture. Clin Neurol Neurosurg 108:67–72
15. Calisaneller T, Ozdemir O, Altinors N (2006) Posttraumatic acute bilateral abducens nerve palsy in a child. Childs Nerv Syst 22:726–728
16. Itshayek E, Goldman J, Rosenthal G et al (2006) Extradural hematoma of the clivus, not limited to the severely injured patient: case report and review of the literature. J Trauma 60:417–420
17. Vera M, Navarro R, Esteban E et al (2007) Association of atlanto-occipital dislocation and retroclival haematoma in a child. Childs Nerv Syst 23:913–916
18. Khan N, Zumstein B (2000) Transverse clivus fracture: case presentation and significance of clinico-anatomic correlations. Surg Neurol 54:171–177
19. Ahn ES, Smith ER (2005) Acute clival and spinal subdural hematoma with spontaneous resolution: clinical and radiographic correlation in support of a proposed pathophysiological mechanism. Case report. J Neurosurg 103:175–179
20. Tubbs RS, Griessenauer CJ, Hankinson T et al (2010) Retroclival epidural hematomas: a clinical series. Neurosurgery 67:404–406, discussion 406–407
21. Meoded A, Singhi S, Poretti A et al (2011) Tectorial membrane injury: frequently overlooked in pediatric traumatic head injury. AJNR Am J Neuroradiol 32:1806–1811
22. Yama N, Kano H, Nara S et al (2007) The value of multidetector row computed tomography in the diagnosis of traumatic clivus epidural hematoma in children: a three-year experience. J Trauma 62:898–901
23. Garton HJ, Gebarski SS, Ahmad O et al (2010) Clival epidural hematoma in traumatic sixth cranial nerve palsies combined with cervical injuries. J Neuroophthalmol 30:18–25
24. Ratilal B, Castanho P, Vara Luiz C et al (2006) Traumatic clivus epidural hematoma: case report and review of the literature. Surg Neurol 66:200–202, discussion 202
25. Fuentes S, Bouillot P, Dufour H et al (2000) Occipital condyle fractures and clivus epidural hematoma. Case report. Neurochirurgie 46:563–567
26. Petit D, Mercier P (2011) Regarding 'retroclival epidural hematomas: a clinical series'. Neurosurgery 68:598–599, author reply E599
27. Myers DJ, Moossy JJ, Ragni MV (1995) Fatal clival subdural hematoma in a hemophiliac. Ann Emerg Med 25:249–252
28. Grabb BC, Frye TA, Hedlund GL et al (1999) MRI diagnosis of suspected atlanto-occipital dissociation in childhood. Pediatr Radiol 29:275–281
29. Tubbs RS, Kelly DR, Humphrey ER et al (2007) The tectorial membrane: anatomical, biomechanical, and histological analysis. Clin Anat 20:382–386
30. Casey D, Chaudhary BR, Leach PA et al (2009) Traumatic clival subdural hematoma in an adult. J Neurosurg 110:1238–1241
31. Ayberk G, Ozveren MF, Aslan S et al (2011) Subarachnoid, subdural and interdural spaces at the clival region: an anatomical study. Turk Neurosurg 21:372–377
32. Ahn SS, Mantello MT, Jones KM et al (1992) Rapid MR imaging of the pediatric brain using the fast spin-echo technique. AJNR Am J Neuroradiol 13:1169–1177
33. Becco de Souza R, Brasileiro de Aguiar G, Sette Dos Santos ME et al (2011) Retroclival epidural hematoma in a child affected by whiplash cervical injury: a typical case of a rare condition. Pediatr Neurosurg 47:288–291
34. Vinchon M, Noule N, Tchofo PJ et al (2004) Imaging of head injuries in infants: temporal correlates and forensic implications for the diagnosis of child abuse. J Neurosurg 101:44–52
35. Tung GA, Kumar M, Richardson RC et al (2006) Comparison of accidental and nonaccidental traumatic head injury in children on noncontrast computed tomography. Pediatrics 118:626–633
36. Bradford R, Choudhary AK, Dias MS (2013) Serial neuro imaging in infants with abusive head trauma: timing abusive injuries. J Neurosurg Pediatr 12:110–119
37. Case ME (2008) Forensic pathology of child brain trauma. Brain Pathol 18:562–564
38. Shaw DW, Weinberger E, Brewer DK et al (1996) Spinal subdural enhancement after suboccipital craniectomy. AJNR Am J Neuroradiol 17:1373–1377
39. Choudhary AK, Bradford RK, Dias MS et al (2012) Spinal subdural hemorrhage in abusive head trauma: a retrospective study. Radiology 262:216–223
40. Tanoue K, Aida N, Matsui K (2013) Apparent diffusion coefficient values predict outcomes of abusive head trauma. Acta Paediatr 102: 805–808
41. Sun PP, Poffenbarger GJ, Durham S et al (2000) Spectrum of occipitoatlantoaxial injury in young children. J Neurosurg 93: 28–39