Epidural hematoma in children: Do cranial sutures act as a barrier?

Hématomes extraduraux de l’enfant : les sutures agissent-elles comme une barrière ?

T.A.G.M. Huisman, F.T.C. Tschirch

Department of Diagnostic Imaging, University Children’s Hospital, Zürich, Switzerland
Division Pediatric Radiology, Russel H. Morgan Department of Radiology and Radiological Science, Johns Hopkins Hospital, 600 North Wolfe Street, Nelson basement, B-173, Baltimore, MD 21287-0842, USA

Summary
Objectives. — Epidural hematoma (EDH) is secondary to laceration of meningeal vessels (arteries or veins), diploic veins or dural sinuses in head injuries. It is widely believed that EDH does not cross cranial sutures, allowing its differentiation from subdural hematoma (SDH). The goal of this study was to determine the percentage of EDH that crosses cranial sutures.

Methods. — Fifty-seven children with at least one EDH lesion were included in the study. CT examination was performed in all patients using a spiral CT scanner and a dedicated children’s protocol. The number, location and size of EDH and their anatomical relationship to cranial sutures were analyzed by consensus between two radiologists.

Results. — Retrospective data analysis showed that, in 11% of children, EDH crossed cranial sutures. Factors that may explain suture crossing are fractures traversing cranial sutures and posttraumatic cranial suture diastasis.

Conclusion. — Our study showed that hematoma extending across a suture may not always allow differentiation between EDH and SDH.

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MOTS CLÉS
Hématomes extraduraux ; Sutures crâniennes ; Traumatisme crânien ; Enfants

Résumé
Objectifs. — Les hématomes extraduraux (EDH) sont secondaires à la laceration par traumatisme crânien des vaisseaux méningés (artères ou veines), de veines diploïques ou de sinus veineux. Il est classique de penser que les EDH ne franchissent pas les sutures crâniennes, ce qui permet de différencier les hématomes sous-duraux (SDH) des EDH. L’objectif de cette étude était de déterminer quel pourcentage d’EDH franchit les sutures crâniennes.

Méthodes. — Cinquante-sept enfants avec au moins un EDH ont été inclus dans cette étude. Les examens scanographiques ont été réalisés chez tous les patients sur un scanner spiralé selon un
Introduction

Epidural hematoma (EDH) occurs most frequently secondary to laceration of meningeal vessels, diploic veins or dural sinuses in traumatic head injuries with skull fractures [1–3]. Blood extravasates into the ‘‘virtual’’ epidural space between the inner tabula of the skull and its corresponding periosteal layer, the dura mater. The dura mater adheres tightly to the inner tabula of the calvaria, but is pulled away by hematoma. The tight dural attachment to the skull results in the characteristic biconvex shape of most EDH. In about 10% of cases, EDH occurs in the absence of a fracture. EDH may be of arterial or venous origin. Most arterial EDH occurs in the temporoparietal region, the location at which the middle meningeal artery is especially vulnerable. Venous EDH is much less common and usually results from laceration of dural venous sinuses, or injury to meningeal or diploic veins. For this reason, venous EDH is often adjacent to a dural sinus, especially when a fracture traverses the involved dural sinus.

Arterial EDH is more frequent in older children and adolescents, whereas venous EDH is somewhat more frequently seen among younger children. However, in general, EDH is less common in children than in adults, except for posterior fossa EDH, which is more often seen in children than in adults and usually as a result of laceration of the dural sinuses [4]. In addition, EDH in children is less frequently accompanied by skull fracture, as the pediatric skull is more elastic and compliant than the adult skull [1]. In neonates, up to 50% of EDH will not require surgery and can be treated conservatively. In older children as with the adult population, small EDH with no significant compression of adjacent brain structures or neurological deficit can be treated conservatively with careful patient monitoring. Large EDH, however, requires emergency surgical evacuation.

EDH usually results from trauma and is rarely due to non-accidental injury. In addition, EDH may arise in hematological disorders or intracranial tumors. In the neonatal period, EDH can be seen after a traumatic delivery. Like EDH, subdural hematoma (SDH) most usually results from trauma too. However, SDH are frequently observed in non-accidental injury such as shaken baby syndrome. SDH tends to resolve spontaneously, but still requires follow-up imaging.

It is widely accepted that EDH does not cross cranial sutures because the periosteal layer of the dura is tightly adherent to the cranial sutures [1–4]. This imaging characteristic is used to distinguish EDH from SDH on computed tomography (CT) or magnetic resonance imaging (MRI). In contrast, SDH typically crosses suture lines, although exceptions are seen along the sagittal suture and tentorium cerebelli. In our experience, EDH occasionally extends beyond cranial sutures. Consequently, the goals of this retrospective study of 57 children with proven EDH were:

- to determine the frequency with which EDH crosses cranial sutures;
- to obtain information on the relationships between the size/location and distribution of EDH.

Materials and methods

Study population

Children were selected by a computer-assisted search through all radiological reports of CT examinations performed at a major university children’s hospital, covering a continuous time period of 30 months. Patients were included if an EDH was diagnosed on CT. A total of 57 children (mean age 7.0 years, age range 6 months to 15 years, 8 months) were included in the study, each of whom had at least one EDH; 23 patients were female, and 34 were male. In all cases, the indication for CT was to rule out intracranial lesions following an acute traumatic head injury. As no examination was repeated and the study design did not involve any secondary patient contact, no approval by the local ethics committee was required.

Computed tomography

All CT examinations were performed according to the departmental imaging protocols for acute head injuries. Depending on the age of the child, 3- or 5-mm axial slices were scanned, covering the brain from the skull base to the vertex. All images were studied using three different window settings. A classical brain-window setting was used to evaluate the brain parenchyma, a high window setting for hemorrhage was used to depict hyperdense extraaxial hemorrhages adjacent to the hyperdense skull and a bone window setting in combination with a bone algorithm reconstruction was used to study the osseous skull. All CT examinations for the study were performed on a spiral CT scanner with dedicated children’s protocols. Although intravenous contrast-media injection is not part of our routine imaging protocol, its use is considered in cases where fractures cross the dural sinuses or when dural sinuses are displaced by a large EDH.
Image analysis

All 57 CT examinations were analyzed by consensus between a general radiologist and a pediatric neuroradiologist. The readers reevaluated the CT scans systematically, according to a predetermined evaluation protocol:

- the number, location (left vs right, infra- vs supratentorial, frontal, parietal, temporal, occipital), shape (convex vs non-convex) and density (hyper-, iso- or hypodense, or mixed) of the EDH were assessed;
- the size of the EDH was graded as mild (minimal or no displacement of adjacent brain structures), moderate (compression of adjacent brain tissue or ventricular system, but without midline shift) or severe (compression of adjacent brain tissue or ventricular system in combination with midline shift). In addition, the maximum width and extent (craniocaudal and anteroposterior) of the EDH was measured in millimeter;
- the anatomical relationship between the EDH and cranial sutures (coronal, lambdoidal and sagittal sutures) was studied, and classified as:
  ◦ distant from the nearest cranial suture,
  ◦ reaching the nearest cranial suture,
  ◦ crossing the nearest cranial suture;
- the presence and location of fracture lines were noted;
- the presence of additional posttraumatic hemorrhage, including intraparenchymal, subarachnoid or subdural bleedings, was recorded.

Statistical analysis was performed using a $t$ test to determine whether the size, location and density of the EDH that traversed sutures were statistically significantly different from those of EDH that did not cross sutures.

Results

Our 57 studied children had a total of 63 EDH: 51 patients had a single EDH; and six patients had two EDH each (ipsilateral in four cases, bilateral in two). There was no side preference (left: $N = 31$; right: $N = 32$). Altogether, 43% of the EDH were parietal ($N = 27$); 38% were frontal ($N = 24$); 24% were temporal ($N = 15$) and the remainder was either infratentorial ($N = 3$; 5%) or occipital ($N = 1$; 1.5%). Seven cases (11%) involved two regions.

In all cases, the EDH showed the characteristic biconvex shape.

The majority of EDH ($N = 47$; 75%) was hyperdense, while the remaining 16 (25%) were a combination of hyper- and hypodense. No hypodense EDH was seen.

About half of the EDH were mild in size ($N = 33$; 52%), while 33% ($N = 21$) were classified as moderate and 14% ($N = 9$) as severe. The mean width was 14 mm (range 3—44 mm), the mean craniocaudal size was 44 mm (range 10—126 mm) and the mean anteroposterior extent was 42 mm (range 15—116 mm).

Most of the EDH ($N = 42$; 67%) had extents that were limited by cranial sutures. Twenty-seven (43%) had reached the coronal suture, 33% ($N = 21$) the lambdoidal suture and 3% ($N = 2$) the sagittal suture. In eight cases, the EDH (13%) had reached two cranial sutures, and seven (11%) had crossed cranial sutures. Of these, five had crossed the coronal suture, one the lambdoidal suture and one the sagittal suture (Fig. 1). Fourteen EDH (22%) were distant from cranial sutures.

The frequency of fusion of the cranial sutures (71%) was the same in both groups ("suture-crossing" EDH vs "suture-adjacent" EDH).

The mean maximum width of the EDH that crossed cranial sutures was 57.4 mm (range 30—80 mm) compared with...
Figure 2  Axial CT images from a soft-tissue window setting (A) and bone algorithm (B) of a six-year-old girl with a right frontolateral EDH that crosses the coronal suture. The hyperdense hematoma (A) shows a "waist-line" indentation at the level of the coronal suture. Bone CT image (B) reveals posttraumatic diastasis of the right coronal suture.

51.9 mm (range 20–126 mm) in the 42 EDH that reached, but did not cross, cranial sutures. The six that crossed cranial sutures showed a "waistline" appearance at the point of crossing (Fig. 2).

Evaluating the seven children with EDH that crossed cranial sutures, two were considered mild (28%), four were moderate (57%) and one was severe (14%).

The mean age of the suture-crossing group was 8.64 years whereas the mean age in the suture-adjacent group was 7.13 years. Five of the seven suture-crossing EDH were frontal, one was temporal and one was infratentorial. In four of these seven cases, an adjacent skull fracture was present whereas, in two of the seven, diastasis of the crossed sutures were seen.

In 52 children, an accompanying skull fracture was present. In 17 cases, the fracture was parietal or temporal, while 16 were frontal and two were occipital.

Additional posttraumatic findings included subgaleal hematoma in 19 children, subarachnoid hemorrhage in three and SDH in two. In addition, four children showed intraparenchymal hemorrhage and two had shearing injuries.

Discussion

EDH is seen in traumatic head injury with skull fractures. A "lucid" or symptom-free interval may be present. The typical biconvex shape differentiates EDH from other types of intracranial hemorrhage such as SDH. The tight adherence of the periosteal layer of the dura to the inner tabula and cranial sutures explains the shape of the EDH, and is believed to prevent extension across suture lines. Exceptions to this rule may be encountered along the sagittal suture because, at this location, the periosteal layer forms the outer wall of the superior sagittal sinus [5]. Occasionally, heterogeneous low-density foci may appear in an acute EDH lesion, indicating active extravasation of fresh, unclotted blood. Known as the "swirl sign" [5—7], this has been reported to correlate with a poor outcome [8]. EDH may be of arterial and venous etiology: the former usually results from laceration of the middle meningeal artery while venous EDH may result from lacerations of diploic veins or dural sinuses.

In contrast to the widespread idea that EDH do not cross cranial sutures, our results show that a small percentage (11%) can extend beyond cranial sutures. This may be of diagnostic and therapeutic consequence. EDH and SDH each has a different natural history and prognosis. EDH may present with a lucid interval, followed by progressive neurological symptoms due to delayed, but occasionally rapid, expansion of the EDH (10–25% of cases). Close clinical monitoring and possible repeat CT examinations are mandatory during the first 24–36 hours [9]. Rapid progression of EDH may be life-threatening and should prompt emergency surgical evacuation. SDH usually has a more chronic presentation and rarely presents with acute, life-threatening, delayed expansion. For this reason, making the correct differential diagnosis between EDH and SDH is essential for establishing the optimal monitoring and treatment options, especially when treatment options vary widely; these options include non-invasive conservative protocols, minimally invasive borehole evacuation and major neurosurgical interventions with craniotomy for hematoma evacuation. Our data show that EDH should not be excluded if the hematoma does cross sutures as this can occur in 11% of EDH cases.

If minimally invasive surgical decompression or evacuation is considered, the neurosurgeon needs to be informed that single borehole trepanation may not suffice. The neurosurgeon should be aware that two boreholes, one on each
side of the crossed cranial suture, may be necessary to completely evacuate the EDH.

The reason why a certain percentage of EDH extends beyond cranial sutures is challenging. Risk factors may include the maximum width of the EDH. Our results showed a slightly larger median width for those that crossed cranial sutures (57.4 mm) compared with those that were limited by cranial sutures (51.9 mm). Statistical analyses, however, showed no statistically significant differences between the two groups, although those that crossed cranial sutures were more frequently graded as moderate or severe. This finding supports the hypothesis that the size of the EDH may be related to the probability of its crossing a cranial suture.

The patient’s age or skeletal maturation (suture closure) was not found to be a risk factor. The mean age was similar (8.64 years vs 7.13 years) for the suture-crossing and suture-adjacent groups, respectively, and the frequency of cranial suture closure was also comparable.

In four of the seven EDH that crossed cranial sutures, an adjacent skull fracture was present and, in two of the seven cases, diastasis of the involved suture was seen. So, a fracture extending across a cranial suture or suture diastasis due to trauma may also explain why some EDH will traverse cranial sutures.

The majority of the EDH in our study were located in the frontoparietal region (38% + 43%) whereas, in the literature, the temporoparietal region is reported to be the predominant location. This difference could be due to the fact that we studied a pediatric population whose skull proportions differ from those of adults. In children, the frontoparietal to temporo-occipital ratio is larger than in adults, thereby increasing the chances of traumatic frontoparietal impact.

However, the density and shape of the EDH in our study, as well as the associated posttraumatic findings, matched those previously reported in the literature [3].

Nevertheless, a major limitation of our study is the retrospective design. Also, because the incidence of EDH that cross cranial sutures proved to be relatively small, larger number of patients are necessary to identify the risk factors and trauma mechanisms that could be linked to EDH suture-crossing. Finally, the fact that our hospital is a large university children’s hospital with a dedicated trauma center leads to a selection bias. Prospective, multicenter studies including patients of all ages are needed to determine the true incidence of EDH lesions that cross cranial sutures. In addition, MRI studies may be helpful because the higher soft-tissue resolution and the different types of information obtained from the use of different imaging sequences can provide valuable information.

**Conclusion**

Our retrospective study showed that a small percentage (11%) of trauma-induced EDH can and do cross cranial sutures. Our data show that hematoma extension across a suture may not always allow differentiation between EDH and SDH. Correct differentiation between the two may, however, be essential for appropriate clinical management, including monitoring intervals, follow-up examinations and treatment options. In addition, neurosurgeons may benefit from this essential information if minimally invasive, bore-hole evacuation is considered.

**References**