Original Paper

Pediatric Neurosurgery

Pediatr Neurosurg 2013;49:215–222
DOI: 10.1159/000363193

Received: December 19, 2013
Accepted after revision: April 20, 2014
Published online: July 29, 2014

The Surgical Outcome of Traumatic Extra-Axial Hematomas Causing Brain Herniation in Children

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Key Words
Brain herniation · Children · Epidural hematoma · Intracranial pressure · Subdural hematoma · Outcome

Abstract
Aim: The aim of this study was to assess the surgical outcome and prognostic importance of clinical and radiological data from children operated on under emergency conditions due to an extra-axial hematoma causing brain herniation. ***Methods:*** This retrospective study included 25 children operated on due to herniated traumatic extra-axial hematomas from January 2000 to December 2010. ***Results:*** Of those 25 children, 17 (68%) were diagnosed with subdural hematoma (SDH), 7 (28%) with epidural hematoma (EDH) and only 1 patient (4%) suffered from both SDH and EDH. Overall mortality from a herniated extra-axial hematoma was 44%. The mortality rate for herniated SDH patients was 52.9%, and only 1 patient died from a herniated EDH (14.2%). Low Glasgow coma scale scores at admission, high postoperative intracranial pressure (ICP) values, longer intervals from trauma to surgery, longer durations of brain herniation, the presence of intraoperative brain swelling, larger and thicker hematomas and more displacement of the midline structures and obliteration of the basal cisterns were all correlated with mortality and an unfavorable outcome. ***Conclusions:*** Brain herniation is a serious consequence of traumatic extra-axial hematomas in children, and approximately one third of these patients have the potential for a favorable outcome. We recommend postoperative ICP monitoring to predict outcome and early decompressive surgery when possible for promising results.

Introduction

Head injury is the leading cause of accidental death and disability in children [1]. Severe head injuries may be complicated by subdural hematoma (SDH) or epidural hematoma (EDH). The incidence of SDH in children is higher than that of EDH [2–4]. Acute extra-axial hematomas (SDH and EDH) are among the most common clinical entities of traumatic brain injury encountered in children by neurosurgeons.

Brain herniation due to traumatic hematoma is a factor of grave prognostic significance and may cause catastrophic consequences. To the best of our knowledge, no previous study has focused specifically on the surgical results of traumatic extra-axial hematomas with secondary herniation in children.

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1016–2291/14/0494–0215$39.50/0

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The aim of this retrospective study was to analyze the surgical outcome and prognostic importance of clinical and radiological data of children who were operated on emergently due to brain herniation caused by a traumatic extra-axial hematoma.

Materials and Methods

This retrospective study included 25 children younger than 16 years old who were operated on due to herniated traumatic extra-axial hematomas from January 2000 to December 2010 in a single neurosurgical clinic. The clinical and imaging data were obtained through retrospective review of the medical records and radiographs. The children who were admitted to the hospital with head trauma and underwent surgical evacuation of a herniated extra-axial hematoma were included in our study. Typically, neurological injury is considered irreversible if there is diffuse loss of grey/white matter differentiation observed by computed tomography (CT) scan. The patients with diffuse loss of grey/white matter differentiation were not operated on and were excluded from this study. Extra-axial hematomas were diagnosed by non-contrast-enhanced CT, and the patients were diagnosed with SDH, EDH or both. Anisocoria and lack of pupillary reaction with midline shift on the admission CT were determined to be indicators of a brain herniation.

All the patients were treated according to Advanced Trauma Life Support guidelines. Initial resuscitation involved venous access, endotracheal intubation and mechanical ventilation in all patients. After hemodynamic stabilization, a complete neurological examination was performed. Head CT scan, cervical X-rays and abdominal ultrasonography were performed in all patients. Only the patients with isolated head trauma were included in this study.

Demographic data, the mechanism of trauma, Glasgow coma scale (GCS) score at the time of admission, pupillary reactivity and the duration of intensive care unit (ICU) stay were collected from the medical records. A ventricular or parenchymal fiber-optic intracranial pressure (ICP) monitor catheter (Camino, Integra Life Science Corporation, Plainsboro, N.J., USA, or Codman, Codman and Shurtleff Incorporation, Raynham, Mass., USA) was placed in all patients during the surgery to assist with postoperative management. The patients whose postoperative ICP data were missing or in whom no ICP monitor was placed were excluded from the study. The ICP data were recorded on an hourly basis in the patient's documentation by the ICU nurses. If a high ICP peak was observed, this was also recorded and included in the data analysis for that time point. We evaluated the mean values of the entire ICP monitoring period postoperatively in hourly measurements.

Brain herniation syndromes, as evidenced by neurological and radiological examinations, were classified as unilateral or bilateral uncal herniation. Unilateral uncal herniation was defined as cases of mydriasis ipsilateral to the hematoma along with contralateral hemiparesis or hemiplegia. Bilateral uncal herniation was recognized by the presence of bilateral fixed and dilated pupils and no extremity response or decerebrate posturing.

The time intervals from the time of trauma to the time of hematoma evacuation, as well as the entire surgical operation times and duration of brain herniation, were recorded. The hematoma evacuation time was estimated to take place 30 min after the skin incision. The length of the period of brain herniation was defined as the time period from when anisocoria was first documented to the time of the hematoma evacuation.

The treatment in the preoperative period included early intubation, sedation and hemodynamic resuscitation. All patients were hyperventilated and received 1 g/kg mannitol and 20 mg/kg phenytoin. These preoperative regimens had no effect on brain herniation status.

All patients were operated on by three senior trauma surgeons. The surgeries consisted of evacuation of the hematoma via craniotomy (CO) or craniectomy (CE) with duraplasty depending on the surgeons' intraoperative judgment. Operation records were also reviewed to determine if intraoperative brain swelling was noted or not.

All the patients were treated with the same postoperative treatment regimen. Postoperatively, general procedures such as 30° elevation and neutral positioning of the head, avoidance of jugular venous obstruction, treatment of fever, maintenance of normovolemia, normoxia and normocarbia, preservation of adequate sedation and analgesia were applied. Mannitol (0.5–1 g/kg every 4–6 h) was used as an osmotic agent. Antiepileptics and antibiotics were administered depending on individual patient characteristics.

The locations of the lesions were verified and recorded from both CT and operative findings. The location of the hematoma was described as the lobe that contained most of the hematoma. Hematoma volume was calculated by the empirical volume formula (0.5 × height × depth × length) using the depth and length measurements of the CT slice with the largest area of clot [5]. Hematoma thickness was measured as the largest vertical distance between the cortex and the internal tabula of the bone. The midline shift was measured as the largest perpendicular distance between an imaginary reference point at the intersection of the frontal crest and the protuberantia occipitalis interna and the most shifted point of the septum pellucidum. The other variables analyzed by CT scan included associated lesions, such as traumatic subarachnoid hemorrhage or brain contusion and obliteration of the basal cisterns.

Functional outcome was evaluated 6 months after discharge from the hospital according to the Glasgow outcome scale (GOS) score, as follows: 5 = good recovery, 4 = moderate disability, 3 = severe disability, 2 = vegetative stage and 1 = death [6]. The patients were declared deceased when cardiac arrest occurred with no response to at least 45 min of resuscitation. Good recovery (GOS score 5) or moderate disability (GOS score 4) were referred to as 'favorable outcomes', whereas the remaining 3 categories were classified as 'unfavorable outcomes'.

Data analysis was performed by using SPSS for Windows, version 11.5 (SPSS Inc., Chicago, Ill., USA). The Shapiro-Wilk test determined if the distributions of the continuous variables were normal. Data are shown as the mean ± SD or median (range), as appropriate.

The mean differences between the groups were evaluated by Student's t test. The Mann-Whitney U test was used for the comparisons of median values. Nominal data were analyzed by Pearson's χ^2 test, Fisher's exact test or the likelihood ratio test, as appropriate.

A p value of less than 0.05 was considered statistically significant.

Results

Twenty-five children with herniated extra-axial hematomas were treated surgically within the study period. Of those 25 children, 17 (68%) were diagnosed with SDH and 7 (28%) with EDH; only 1 patient (4%) suffered from both SDH and EDH. Overall mortality from a herniated extra-axial hematoma was 44%. The mortality rate for herniated SDH patients was 52.9%, and only 1 patient died from a herniated EDH (14.2%), though the difference in the mortality rate between the SDH and EDH patients was not statistically significant (p = 0.08). The patient with both pathologies (SDH in the right hemisphere and EDH in the left) was admitted to the emergency room with bilateral fixed and dilated pupils and a GCS score of 3. This patient died during the first postoperative day. Of the 25 patients overall, only 7 (28%) had a favorable outcome. Significantly more patients diagnosed with SDH (88.2%) experienced an unfavorable outcome compared to the patients diagnosed with EDH (28.5%; p = 0.011).

The age of patients ranged from 1 week to 16 years (9.6 ± 4.7 years), with a median of 12 years. There was no statistical correlation between age and mortality (p = 0.061). However, we found that younger age was correlated with an unfavorable outcome (p = 0.002). There were 13 females (52%) and 12 males (48%). The mortality and unfavorable outcome rates were not significantly different between the sexes (p = 1 and 0.821, respectively).

Motor vehicle accidents were the leading cause of trauma (n = 9, 36%), followed by falls (n = 8, 32%), pedestrian injuries (n = 5, 20%), television falls (n = 2, 8%) and bicycle accidents (n = 1, 4%). The mechanism of trauma showed no correlation with mortality (p = 0.073) or functional outcome rates (p = 0.086).

The demographic data of the study cohort are summarized in table 1.

Table 1. Demographic characteristics of the patients

	Number	%
Sex		
Male	12	48
Female	13	52
Diagnosis		
SDH	17	68
EDH	7	28
Both SDH and EDH	1	4
Mechanism of injury		
Motor vehicle accident	9	36
Fall	8	32
Pedestrian injury	5	20
Television fall	2	8
Bicycle accident	1	4
Location of the hematoma		
Frontal lobe	17	68
Temporal lobe	4	16
Parietal lobe	3	12
Posterior fossa	1	4

The median admission GCS scores were 3 (range 3–5) for the patients who died and 5 (range 3–8) for the patients who survived; the patients who had lower median GCS scores at admission had higher mortality rates (p < 0.001). The median GCS score at admission was significantly higher in patients who achieved a favorable outcome (6, range 3–8) than in patients who had an unfavorable outcome (p = 0.004).

Patients with bilateral unresponsive pupils (bilateral uncal herniation) had a 71.4% mortality rate, and patients with unilateral unresponsive pupils (ipsilateral uncal herniation) had a 33.3% mortality rate. This difference was not statistically significant (p = 0.177). Only 2 patients with bilateral unresponsive pupils survived; 1 had a GOS score of 3 and the other had a score of 5. Both patients were operated on within 1 h of admission. As expected, patients with bilateral unresponsive pupils had higher unfavorable outcome rates (71.4%) than the patients with unilateral unresponsive pupils (66.6%). This difference was not statistically significant (p = 0.626).

Patients who survived a herniated extra-axial hematoma had a longer duration of ICU stay than the patients who died (p = 0.008). The duration of ICU stay did not have an effect on outcome (p = 0.198).

Mortality rate was highly correlated with mean postoperative ICP values (p < 0.001). Patients who died had significantly higher postoperative ICP values (mean 29.5 mm Hg, range 23–35) compared with the patients who survived (mean 22 mm Hg, range 13–28). Unfavorable outcome was also correlated with mean postoperative ICP values (p < 0.001). Patients with a favorable outcome had significantly lower mean postoperative ICP values (mean 15 mm Hg, range 13–22) compared to patients with an unfavorable outcome (mean 27 mm Hg, range 22–35).

A longer interval from the time of trauma to the time of hematoma evacuation was correlated with a high mortality rate (p = 0.03) and high unfavorable outcome rate (p = 0.003). The patients who were operated on within 2 h of the trauma showed only a 25% mortality rate,

Table 2. Variables related to mortality

Variable	Surviving patients (n = 14; 56%)	Deceased patients (n = 11; 44%)	p value
Diagnosis			0.08
SDH	8 (57.1%)	9 (81.8%)	
EDH	6 (42.9%)	1 (9.1%)	
Both SDH and EDH	–	1 (9.1%)	
Age, years	11±4	7.8±5.2	0.061
Sex			0.821
Male	7 (50%)	5 (45.5%)	
Female	7 (50%)	6 (54.5%)	
Admission GCS	5 (3–8)	3 (3–5)	<0.001
Pupil reactivity			0.177
Bilaterally unresponsive (bilateral uncal herniation)	2 (14.3%)	5 (45.5%)	
Unilaterally unresponsive (ipsilateral uncal herniation)	12 (85.7%)	6 (54.5%)	
Duration of ICU stay, days	11.5 (2–22)	3 (0–15)	0.008
Postoperative ICP, mm Hg	22 (13–28)	29.5 (23–35)	<0.001
Time to surgery			0.03
≤2 h	6 (42.9%)	2 (18.2%)	
2–4 h	5 (35.7%)	1 (9.1%)	
≥4 h	3 (21.4%)	8 (72.7%)	
Operation time, h	1.75 (1–2)	2 (1–4)	0.572
Herniation duration, h	1 (0.5–2)	2 (0.5–4)	0.038
Surgery			<0.001
CE	5 (35.7%)	11 (100%)	
CO	9 (64.3%)	–	
Intraoperative brain swelling			0.008
Documented	7 (50%)	11 (100%)	
Not documented	7 (50%)	–	
Hematoma location			0.073
Frontal lobe	8 (57.1%)	9 (81.8%)	
Temporal lobe	4 (28.6%)	–	
Parietal lobe	2 (14.3%)	1 (9.1%)	
Posterior fossa	–	1 (9.1%)	
Hematoma volume, ml	102.5 (74–165)	140 (110–190)	<0.001
Hematoma thickness, mm	16 (12–25)	27 (16–32)	<0.001
Midline shift, mm	12 (5–19)	19 (11–28)	<0.001
Coincidental lesion			0.419
None	10 (71.4%)	5 (45.5%)	
SAH	2 (14.3%)	3 (27.3%)	
Contusion	2 (14.3%)	3 (27.3%)	
Obliteration of basal cisterns			<0.001
Yes	5 (35.7%)	11 (100%)	
No	9 (64.3%)	–	

SAH = Subarachnoid hemorrhage.

Table 3. Variables related to functional outcome

Variable	Favorable outcome (n = 7; 28%)	Unfavorable outcome (n = 18; 72%)	p value
Diagnosis			0.011
SDH	2 (28.6%)	15 (83.3%)	
EDH	5 (71.4%)	2 (11.1%)	
Both SDH and EDH	–	1 (5.6%)	
Age, years	11.5±2.7	8.8±5.2	0.002
Sex			1.000
Male	3 (42.9%)	9 (50%)	
Female	4 (57.1%)	9 (50%)	
Admission GCS	6 (3–8)	3.5 (3–6)	0.004
Pupil reactivity			0.626
Bilaterally unresponsive (bilateral uncal herniation)	1 (14.3%)	6 (33.3%)	
Unilaterally unresponsive (ipsilateral uncal herniation)	6 (85.7%)	12 (66.7%)	
Duration of ICU stay, days	9 (2–22)	6 (0–21)	0.198
Postoperative ICP, mm Hg	15 (13–22)	27 (22–35)	<0.001
Time to surgery			0.003
≤2 h	5 (71.4%)	3 (16.7%)	
2–4 h	2 (28.6%)	4 (22.2%)	
≥4 h	–	11 (61.1%)	
Operation time, h	1.5 (1–2)	2 (1–4)	0.357
Herniation duration, h	0.5 (0.5–1)	1 (0.5–4)	0.017
Surgery			0.058
CE	2 (28.6%)	14 (77.8%)	
CO	5 (71.4%)	4 (22.2%)	
Intraoperative brain swelling			0.066
Documented	3 (42.9%)	15 (83.3%)	
Not documented	4 (57.1%)	3 (16.7%)	
Hematoma location			0.086
Frontal lobe	4 (57.18%)	13 (72.2%)	
Temporal lobe	3 (42.9%)	1 (5.6%)	
Parietal lobe	–	3 (16.7%)	
Posterior fossa	–	1 (5.6%)	
Hematoma volume, ml	88 (74–110)	122 (95–190)	<0.001
Hematoma thickness, mm	16 (12–21)	24 (13–32)	0.004
Midline shift, mm	10 (5–14)	17 (11–28)	<0.001
Coincidental lesion			0.108
None	6 (85.7%)	9 (50%)	
SAH	–	5 (27.8%)	
Contusion	1 (14.3%)	4 (22.2%)	
Obliteration of basal cisterns			<0.001
Yes	–	16 (88.9%)	
No	7 (100%)	2 (11.1%)	

Favorable outcome was defined as a GOS score of 3, 4 or 5. Unfavorable outcome was defined as a GOS score of 1 or 2. SAH = Subarachnoid hemorrhage.

whereas the patients who were operated on more than 4 h after the trauma had a 72.7% mortality rate. Furthermore, 62.5% of the patients who were operated on within 2 h of the trauma had a favorable outcome, and none of the patients who were operated on more than 4 h after the trauma had a favorable outcome. There were only 3 survivors who were operated on more than 4 h after the trauma; 2 of these 3 patients had a GOS score of 2 and 1 had a GOS score of 3.

There was no correlation between the length of the operation and mortality (p = 0.572) or unfavorable outcome (p = 0.357).

The duration of the brain herniation was strongly correlated with mortality and unfavorable outcome; i.e. lon-

Table 4. Clinical and radiological data relevant to the 14 surviving patients

Age, years	Sex	Diag-nosis	GCS at admission	Pupillary status	Duration of ICU stay, days	Mean ICP, mm Hg	Time from trauma to surgery, h	Duration of herniation, h	Surgery	Intraoperative brain swelling	Coincidental lesion	Obliteration of basal cisterns	GOS
12	M	SDH	4	ipsilateral UR	6	25	5	0.5	CE	documented	SAH	yes	2
15	F	EDH	4	ipsilateral UR	11	26	4	2	CO	documented	SF	yes	2
2	F	SDH	4	ipsilateral UR	13	26	2	1	CO	ND	contusion	yes	2
16	M	SDH	5	ipsilateral UR	5	28	4	1	CE	documented	NA	yes	3
5	F	SDH	6	ipsilateral UR	12	23	3	1	CO	ND	NA	no	3
11	M	SDH	5	ipsilateral UR	21	22	3	1	CE	documented	SAH	yes	3
12	F	SDH	4	bilateral UR	19	22	1	1	CO	ND	NA	no	3
6	F	SDH	5	ipsilateral UR	6	18	3	0.5	CE	documented	contusion, SF	no	4
12	M	EDH	7	ipsilateral UR	2	14	3	0.5	CO	ND	NA	no	4
11	F	EDH	7	ipsilateral UR	9	15	2	1	CO	ND	NA	no	4
11	M	SDH	6	ipsilateral UR	21	22	2	0.5	CO	documented	SF	no	4
13	F	EDH	6	ipsilateral UR	19	13	2	1	CO	ND	NA	no	5
14	M	EDH	8	ipsilateral UR	6	15	2	0.5	CO	ND	NA	no	5
14	M	EDH	3	bilateral UR	22	20	1	0.5	CE	documented	NA	no	5

UR = Unresponsive; NA = not available; ND = not documented; SAH = subarachnoid hemorrhage; SF = skull fracture.

ger periods of brain herniation were correlated with higher incidences of mortality (p = 0.038) and unfavorable outcomes (p = 0.017).

None of the patients whose hematoma was evacuated via CO died. However, patients whose hematoma was evacuated via CE had a 68.7% mortality rate. This difference was statistically significant (p < 0.001). There were no statistically significant differences in the functional outcome measure between patients whose hematoma was evacuated via CO or CE (p = 0.058).

Intraoperative brain swelling was correlated with high mortality (p = 0.008) but not with unfavorable outcome (p = 0.066).

The most common hematoma location was the frontal lobe (n = 17, 68%), followed by the temporal lobe (n = 4, 16%), parietal lobe (n = 3, 12%) and posterior fossa (n = 1, 4%). The location of the hematoma had no effect on mortality (p = 0.073) or functional outcome (p = 0.086).

Hematoma volume was closely related to mortality and unfavorable outcome; i.e. larger hematoma volumes were correlated with higher incidences of mortality (p < 0.001) and unfavorable outcomes (p < 0.001). Similarly, thicker hematomas were correlated with higher incidences of mortality (p < 0.001) and unfavorable outcomes (p = 0.004). Greater displacement of the midline structures was significantly related to high mortality (p < 0.001) and unfavorable outcomes (p < 0.001).

Coincidental lesions such as subarachnoid hemorrhage and contusion were correlated neither with mortality (p = 0.419) nor unfavorable outcome (p = 0.108). The obliteration of the basal cisterns was significantly correlated with both high mortality (p < 0.001) and high unfavorable outcome rates (p < 0.001).

None of the postoperative CTs revealed residual or de novo hematoma formation. When compared with the preoperative CT findings, there was no noteworthy change observed in the postoperative CT findings in any patient.

Variable analyses relevant to mortality and functional outcome are summarized in tables 2 and 3, respectively. Clinical and radiological data of the surviving patients are summarized in table 4.

Discussion

Following head injury, extra-axial hematomas such as SDH and EDH can occur. The most important neurosurgical problem with an extra-axial hematoma is the occurrence of a brain herniation due to rapid enlargement of the hematoma [7, 8]. Brain herniation is a catastrophic factor and can lead to mortality via brainstem ischemia [9]. Brain herniation had previously been considered the point of no return and an extremely inauspicious sign. However, reports of successful reversal of brain herniation from different etiologies have been published [9–15]. To the best of our knowledge, our retrospective study is the first report of the surgical outcome of herniated traumatic extra-axial hematomas in children.

The overall mortality from brain herniation had been reported as 30–60%, and a favorable outcome has been reported in 9–25% of patients [9, 14, 15]. Consistent with previous studies of brain herniation from different pathologies, the overall mortality in our study of children suffering from a herniated extra-axial hematoma was 44%, and only 28% of the patients had a favorable outcome. Mortality rates for herniated SDH and EDH were 52.9 and 14.2%, respectively. Of the patients with a herniated SDH, 88.2% experienced an unfavorable outcome. Only 28.5% of patients with a herniated EDH had an unfavorable outcome. The results of our study concluded that brain herniation from an SDH causes significant mortality and an unfavorable outcome.

Previous studies reported that a younger age is correlated with a worse outcome in pediatric head trauma patients [16–18]. In our study, we also found that younger age is correlated with an unfavorable outcome. However, no correlation between age and mortality was determined.

Previous studies of pediatric head trauma revealed that falls were the most common cause of trauma [4, 19, 20]. However, we found that motor vehicle accidents were the leading cause of trauma in patients with a herniated extra-axial hematoma. Furthermore, the mechanism of trauma did not have a significant effect on either mortality or functional outcome.

In our study, all patients with herniated extra-axial hematomas were comatose and had GCS scores equal to or lower than 8. As expected, we concluded that low initial GCS scores were correlated with high mortality and an unfavorable outcome.

Patients suffering from bilateral uncal herniation had a 71.4% mortality rate and an 85.7% unfavorable outcome rate. Despite these high values, no statistically significant difference was found between the type of herniation and outcome. We believed this was due to the small number of patients.

Our data revealed that patients who survived had longer ICU stays than the patients who died. This was due to the poor conditions of the patients who died; also, early death of a patient caused an early discharge from the ICU.

High ICP is the most frequent cause of death and disability after a severe traumatic brain injury [21–23]. ICP monitoring is recommended by all available guidelines for the management of severe traumatic brain injury [24, 25]. There are only a few studies available in which postoperative ICP and its relation to outcome was documented [26]. In our study, we monitored all patients with continuous postoperative ICP monitors. The data obtained concluded that high postoperative ICP values are associated with high mortality and unfavorable outcome.

The Brain Trauma Foundation and the Congress of Neurological Surgeons have recommended that surgical evacuation must be performed 'as soon as possible' in the case of brain herniation [27]. In accordance with previous studies, our data showed that earlier decompression of a herniated SDH or EDH was significantly correlated with low mortality and a favorable outcome [28–30]. Patients who were operated on within 2 h of the trauma had only a 25% mortality rate, while patients who were operated on more than 4 h after the trauma had a 72.7% mortality rate. Furthermore, 62.5% of patients who were operated on within 2 h of the trauma had a favorable outcome, and none of the patients who were operated on more than 4 h after the trauma had a favorable outcome. Some authors have reported that the critical time for the herniated brain starts from the onset of symptomatic brain compression [31–33]. In our study, we also demonstrated that a longer duration of brain herniation was correlated with higher incidences of both mortality and unfavorable outcome. Time is the only amendable parameter of all the factors affecting outcome and mortality. As the prognosis of both herniated SDH and EDH was affected by delay of the operation and duration of the brain herniation, we strongly recommend surgery within the shortest possible time and ideally within the first 2 h following trauma.

The mortality rate of patients whose hematomas were evacuated via CE (68.7%) was far higher than via CO (0%). Additionally, intraoperative brain swelling significantly worsened mortality. We believe the high mortality rate of the CE group was due to the high proportion of patients in this group with acute intraoperative brain swelling, which led to the surgeon deciding not to replace the skull bone over the exposed brain.

Our data demonstrated that the size of the hematoma affects outcome. Larger and thicker hematomas cause a higher incidence of both mortality and unfavorable outcome. The degree of midline shift also affected mortality and unfavorable outcome. Obliterated basal cisterns on the initial CT were associated with high mortality and an unfavorable outcome.

This retrospective study concluded that low GCS scores at admission, high postoperative ICP values, longer intervals from trauma to surgery, longer durations of brain herniation, the presence of intraoperative brain swelling, larger and thicker hematomas, greater displacement of the midline structures and the obliteration of the basal cisterns were all correlated with mortality and an unfavorable outcome among children suffering from herniated extra-axial hematomas.

The retrospective evaluation of clinical and radiological data is a clear limitation of this study. Moreover, the number of patients included in this study is comparatively small. The ICP values were measured hourly, and the mean values were used for statistical analysis, which might be another limitation of the study. Longer follow-up with quality-of-life assessments is also needed to provide better conclusions.

Conclusions

We concluded that brain herniation is a serious consequence of traumatic extra-axial hematomas in children, and approximately one third of these patients have the potential for a favorable outcome. We recommend postoperative ICP monitoring to predict outcome and very early decompressive surgery, ideally within 2 h of the trauma, for promising results.

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