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Follow-up of Children after Surgical Evacuation of Extradural Haematomas: Getting it Right First Time

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Abstract

Objective Surgical outcomes for children with an extradural haematoma (EDH) can be excellent. However, neuropsychological outcomes of children after surgery for EDH are sparsely reported, and follow-up for these children is non-standardised. This study describes the follow-up and neuropsychological outcomes of a cohort of children who had surgery for an EDH.

Methods Anonymised data were collated from a prospectively collected cohort of paediatric patients who underwent urgent surgery for EDH at a single neurosurgical centre from March 2007 to May 2021.

Results Thirty-five patients were included in the study. Patients were aged between 5 months and 15 years. Almost all the patients (33/35; 94.2%) had a Glasgow Outcome Score (GOS) of 5 out of 5 upon hospital discharge. No deaths or recurrences were identified. Thirty patients (86%) received at least one follow-up review postoperatively; five patients (14%) had no documented follow-up. Forty percent (12/30) of patients who were followed up had neuropsychological concerns identified. Of these children, only four (33%) received formal neuropsychological review and treatment. Children with a low-presentation Glasgow Coma Scale (GCS) were more likely to develop neuropsychological issues ($p = 0.045$).

Conclusion Children with EDHs can have good surgical outcomes. However, follow-up for these patients can be variable, which may be suboptimal for identifying the neuropsychological issues which can develop in children following head injury. In this study, children remain at risk even when the blood location is extra-axial, as in cases of EDH. All children should, therefore, receive formal follow-up and neuropsychological review after surgery for EDH.

Keywords
- paediatric
- extradural
- haematoma
- neuropsychology
- follow-up

Introduction

Extradural haematomas (EDHs) are responsible for 2 to 3% of all acute traumatic paediatric head injuries.[1,2] Most literature states that children who are unwell or who have a large EDH should receive rapid surgical intervention to ensure optimal surgical outcomes.[3] If operated in a timely manner, most children appear to recover very well

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postoperatively, returning to full-time education and sporting activities.[1,4]

Paediatric EDHs are often discharged from neurosurgical follow-up relatively quickly.[4] However, in other forms of head injury, such as brain contusions and subdural haematomas, it is known that children may develop neuropsychological symptoms that require specialist treatment, such as emotional lability, memory issues, mood disturbance and sleep issues.[5] These complex domains are rarely evaluated as a standard of care in most neurosurgical clinics, and thus, children with these types of head injuries are often also routinely assessed by specialist paediatric neuropsychologists[5,6] and close, multidisciplinary follow-up is often advocated.[7] However, most literature on paediatric EDHs focusses on surgical outcomes such as mortality, recurrence and postoperative motor deficits and does not assess the follow-up or neuropsychological outcomes in children following surgery for these extra-axial haematomas.[4,8] There is also no set guidance to inform the follow-up of paediatric EDH patients, which prompted the current study to evaluate the practice for follow-up and neuropsychological assessments of children who have undergone acute surgery for an EDH in a single tertiary neurosurgical unit in the United Kingdom.

Materials and Methods

A retrospective review of a prospectively maintained and link-anonymised database of all acute paediatric EDH admissions was conducted to screen for all cases of paediatric EDH treated surgically at a single United Kingdom's tertiary paediatric neurosurgery centre. The inclusion criteria were (1) diagnosis of acute traumatic EDH via CT scan in a paediatric (<16 years old) patient and (2) urgent neurosurgical evacuation of the EDH. The study period spanned between March 2007 and May 2021. This retrospective study was performed in-line with the principles stated in the Declaration of Helsinki.

Anonymised clinical data were collated from electronic patient documentation, including patient gender, date of birth, mechanism of injury, admission Glasgow Coma Scale (GCS), neurological and pupillary deficits, date and nature of surgical intervention, postsurgical course, Glasgow Outcome Score (GOS), number and nature of follow-up appointments and evaluation of any clinical or neuropsychological concerns at follow-up. CT scans were reviewed by a consultant neurosurgeon. The location of the EDH, the presence or absence of brain contusions and the presence or absence of skull fractures were noted.

Follow-up appointments were screened using electronic records, noting the clinic in which the reviews were conducted, the median follow-up times, the number of follow-up appointments and the presence of any ongoing physical or psychological concerns at these appointments.

During the study period, children treated surgically for an EDH were referred for review with a paediatric neuropsychologist postoperatively. However, due to appointment constraints during the COVID pandemic and the subsequent departure of the unit's paediatric neuropsychologist, these reviews were paused from 2020 onwards. Therefore, a subcohort of children in this study did not have access to neuropsychological support postoperatively.

Of children who did receive neuropsychological follow-up, each appointment consisted of the child and parents/guardians completing questionnaires about the child's behaviour, mood and cognitive function. Parents/guardians completed the Behaviour Rating Inventory of Executive Function (2nd edition), assessing executive functioning skills and 'metacognitive skills', and a Conners 3 assessment, providing ratings of the child's perceived attention and ability to concentrate.[9,10] Children were asked to self-report via the Revised Children's Anxiety and Depression Scale (RCADS), assessing states of anxiety and low mood in children aged 8 to 18 years.[9,11,12] The neuropsychological review also assessed cognitive skills relating to intellect, memory, processing speed, attention skills, executive functioning skills and academic skills. Recommendations for further treatment considered the results of parental and patient reporting, behavioural observations during assessment, and the assessment scores themselves.

Statistical evaluations were conducted using Fisher's exact test for categorical data. p-values <0.05 were considered statistically significant.

Results

Participants

Thirty-five paediatric acute traumatic EDH cases were identified between March 2007 and May 2021 and included in the study. The majority of patients were male (85.7%; $n=30$), and 14.3% ($n=5$) were female. Age distribution on the date of surgical intervention ranged from 5 months to 15 years, 11 months. The median age on the date of surgery was 9 years. Twenty percent ($n=7$) of patients were <5 years of age on the date of surgical intervention. Forty-six percent ($n=16$) were 5 to 10 years of age, and 12 patients (34.3%) were 10 to 16 years of age on the date of surgery. None of these three age categories was statistically associated with a higher risk of neuropsychological deficits postoperatively.

Mechanisms of Injury

The leading cause of injury was a fall (49%, $n=17$). This included falls from heights, standing height and falls downstairs. Non-motorised and motorised vehicle incidents made up other significant subcohorts of cases in this study (►**Table 1**). There was one child for whom we did not have access to the reported mechanism of injury and was excluded from this section of the analysis. One hundred percent ($n=5$) of female patients in this series suffered a fall as the reported mechanism of injury.

Preoperative Glasgow Coma Scale and Neurology

The lowest GCS of children prior to surgical evacuation was recorded (►**Table 2**). Just over half (58.1%, $n=18$) of patients had a worst presenting GCS of 14 to 15 (mild); almost 10% ($n=3$) had a moderate GCS (9–13); and almost a

Table 1 Breakdown of mechanisms of injury leading to the development of an extradural haematoma

Mechanism of injury	Impact (low, moderate or high)	*n* (%)
Fall from standing height	Low	10 (29.4%)
Fall from arms of an adult	Moderate	1 (2.9%)
Fall downstairs	Moderate	2 (5.9%)
Ran into a table	Moderate	2 (5.9%)
Fall from a height (10 ft)	High	1 (2.9%)
Involving a non-motorised vehicle (bikes and scooters)	High	9 (26.5%)
Involving a motorised vehicle (cars and motorbikes)	High	5 (14.7%)
Sporting accident resulting in direct head trauma	High	2 (5.9%)
No data	–	1 (2.8%)

third ($n = 10$) of children had a severe traumatic brain injury (TBI; presenting GCS 3–8). A severe TBI (preoperative GCS 3–8) was statistically associated with a higher risk of postoperative neuropsychological deficits ($p = 0.0454$).

Fourteen percent ($n = 5$) of the children had neurological deficits on admission. One child had a transient left-hand paraesthesia. One child was bilaterally areflexic in their lower limbs. Another child had severe bilateral upper and lower limb weakness, in addition to Cushing's response. The fourth child had right-sided hemiplegia, and the final child presented with Wernicke's aphasia and right-hand paraesthesia. All of these childrens' neurological deficits resolved immediately after surgery, except for the child exhibiting the Cushing's response. This child had persistent unilateral hemiparesis postsurgery, although this did resolve without further treatment prior to the patient's discharge from the hospital, albeit with residual choreiform movements of those limbs persisting long-term. The presence of preoperative neurological deficits was not associated with postoperative neuropsychological deficits in this study cohort ($p = 1.000$).

Twenty-three percent ($n = 8$) of patients had abnormal pupillary responses upon admission. These included issues such as asymmetrical pupils and bilateral sluggish pupils. Pupillary function normalised postoperatively in all eight patients. Preoperative pupillary dysfunction was not associated with postoperative neuropsychological deficits ($p = 0.083$).

Radiology

All 35 patients received a CT scan on admission to the emergency department. Scans were assessed for haematoma location, presence/absence of brain contusions and presence/absence of skull fractures (►**Table 2**). No patients had bilateral EDHs, and all EDHs were supratentorial. Forty percent ($n = 14$) had a left-sided EDH, and 60% ($n = 21$) had a right-sided EDH. Fourteen percent ($n = 5$) of patients had brain contusions as well as their EDH; four of these children had small cortical contusions, and one had bilateral cerebellar contusions. Skull fractures were present in 74% ($n = 26$) of patients. None of these fractures were depressed in nature. None of these imaging factors had any statistical association with postoperative neuropsychological deficits (►**Table 3**).

Surgical Outcomes

All patients underwent craniotomy for evacuation of their EDH. One patient also underwent insertion of a ventricular drain and subsequent ventriculoperitoneal shunting for posttraumatic hydrocephalus. He achieved a GOS of 4 at discharge from Wales. No follow-up information was available for this child, as he was on holiday at the time of his injury and returned to England for his ongoing rehab and follow-up.

Ninety-four percent ($n = 33$) of patients achieved a GOS of 5 on discharge, and 5.7% ($n = 2$) of patients achieved a GOS of 4. There were no deaths or recurrences in the study cohort. There were no postoperative infections in this study cohort.

Table 2 Perioperative clinical findings and their associations with postoperative neuropsychological issues

Clinical findings	Number of children (%)	Association with postop neuropsychological deficits (*p*-value)
Pupil dysfunction	8 (22.8%)	0.083
Motor deficits	5 (14.3%)	1.000
Preoperative worst GCS		
14–15 (Mild)	18 (51.4%)	0.139
9–13 (Moderate)	3 (8.5%)	1.000
8–3 (Severe)	10 (29%)	**0.0454**
Posttraumatic seizures	2 (5.7%)	0.152

Abbreviation: GCS, Glasgow Coma Scale.
p-values were calculated via Fisher's exact test. $p < 0.05$ was considered significant.

Table 3 Radiological findings from presurgical CT scans and their associations with postoperative neuropsychological issues

Radiological findings	Number of children (%)	Association with postop neuropsychological deficits (*p*-value)
Skull fracture	26 (74.3%)	0.686
Brain contusions	5 (14.3%)	0.152
Side of EDH		
Left	14 (40%)	1.000
Right	21 (60%)	1.000

Abbreviation: EDH, extradural haematoma.
p-values were calculated via Fisher's exact test. $p < 0.05$ was considered significant.

Table 4 Table summarising number of postoperative appointments for the study population

Number of appointments	Number of children (%)
≥5	2 (6.66%)
4	1 (3.33%)
3	2 (6.66%)
2	8 (26.7%)
1	17 (56.7%)
0	5 (16.7%)

Two patients had posttraumatic seizures after their head injury. In one of these patients, the seizures resolved 13 months after surgery, whereas the other patient remained epileptic long-term. Both patients who had seizures also had neuropsychological concerns identified at follow-up ($p = 0.152$; ►**Table 2**).

Follow-up appointments

The median follow-up duration for the study cohort was 4 months (range 0–55 months). Five children in the study population had no follow-up postdischarge from hospital. Of these children, two sustained accidents whilst on holiday in Wales, and as a result, when discharged home to England, no follow-up documentation was available for review in this study. These five children were excluded from subsequent analyses.

Follow-up varied considerably between patients. Despite all being treated surgically for an acute traumatic EDH, there was no discernible pattern to follow-up scheduling. ►**Tables 4** and **5** list the number of follow-up appointments each child received and the departments which conducted their follow-up appointments. Most children who were followed up received a single follow-up appointment ($n = 17$, 56.7%), which was most commonly with a paediatric neurosurgeon ($n = 26$, 86.7%).

Postoperative Neuropsychology

No patients in this study had preoperative neuropsychological diagnoses. Neuropsychological concerns were identified at postoperative follow-up for 12 patients (►**Table 6**), but only four of these children had formal neuropsychology reviews. These children were referred to the neuropsychology department prior to the departure of the paediatric neuropsychologist from the unit.

The most common neuropsychological symptom identified was mood disturbance ($n = 5/12$, 41.6%; ►**Table 6**). Four patients received a formal neuropsychology assessment with a paediatric neuropsychologist. Eight children had follow-up notes which referred to neuropsychology concerns, but no documented assessments with a neuropsychologist have taken place to date. Eleven children with neuropsychological issues were male, and one was female.

Both patients who had posttraumatic seizures had neuropsychological concerns raised at follow-up (►**Table 2**). Children who had a low preoperative GCS (3–8) were more likely to suffer from neuropsychological repercussions than those with a preoperative GCS >8 ($p = 0.0454$; ►**Table 2**). There was no statistically significant association between brain contusions, skull fractures or EDH laterality with the development of postoperative neuropsychological concerns (►**Table 3**).

The first child who received a formal neuropsychological review had surgery at age 5 years, 11 months. The time between injury and neuropsychological review was 70 months, essentially serving as a long-term follow-up review at 6 years postinjury. He was not taking any medications at the time of his neuropsychology review. He

Table 5 Distribution of specialties conducting follow-up appointments

Specialty responsible for follow-up appointments	Number of children seen (%) [total number of appointments]
Paediatric neurosurgery	26 (86.7%) [29]
Paediatric neurology	9 (30.0%) [17]
Paediatric rehabilitation	1 (3.33%) [2]
Paediatric neuropsychology	4 (13.3%) [5]

Table 6 Features of all patients who had neuropsychology concerns identified at follow-up after surgery for extradural haematoma

Age at surgery (years, months)	Preop GCS	GOS on discharge	Number of follow-up appointments	Concerns identified	Number of neuropsychology team reviews
0, 5	8	5	2	Dyslexia, atypical behaviour, unusual seizures (possibly some non-epileptic events)	0
7, 11	5	5	2	Hypersexuality, ADHD-like symptoms	0
14, 1	5	5	1	Paranoia	0
4, 0	14	5	3	Personality change, poor engagement with authority	0
9, 0	3	5	5	Mood disturbance, forgetfulness,	0
5, 11	14	5	2	Mood disturbance, anxiety	1
6, 8	6	5	2	Poor attention, learning difficulties	1
7, 0	14	5	4	Poor communication skills, personality change, mood disturbance, deliberate self-harm	2
1, 5	9	5	6	Poor memory (transient)	0
15, 11	8	4	3	Severe behavioural issues, mood disturbance	1
8, 3	7	5	1	Mood disturbance, poor concentration	0
2, 1	14	5	2	Sleep disturbance	0

Abbreviations: GCS, Glasgow Coma Scale; GOS, Glasgow Outcome Score.

exhibited signs of high levels of anxiety and low mood, noted as a new change since his brain injury, according to his parents. During self-reporting, using the Impact of Events Scale Revised, this child showed no indications of ongoing trauma to suggest a posttraumatic stress spectrum syndrome. This child was fatigued and slow to respond, and the assessments were terminated early by his parents. The examinations that were completed indicated deficits in several areas, such as verbal intellect, processing speed and memory recall. There were also concerns about a lack of self-regulation for his age.

The next neuropsychology assessment was undertaken on a child who had surgery at 6 years, 8 months. The time between injury and neuropsychological review was 29 months (roughly 2 years). The patient was not taking any regular medications at the time of the neuropsychological review. Conners 3rd Edition assessment completed by the child's parents indicated marked levels of inattention and learning difficulties compared with peers of his age. The Impact of Events Scale Revised showed no indication of ongoing trauma. This child was cooperative during the assessment.

The third child assessed by the neuropsychology team was 7 years old. The time between injury and neuropsychological review was 55 months (4.5 years). The patient was not taking any regular medications at the time of the neuropsychological review. His neuropsychological assessment revealed several new executive function issues, mood disturbance and poor verbal intellect. The child also performed acts of deliberate self-harm following his EDH, suggestive of ongoing posttraumatic stress-related issues. At his most recent follow-up (27 months postsurgery), these symptoms, including his mood and school performance, had improved.

The final child who received a neuropsychological review was 15 years old. He was slow to recover following his craniotomy. Whilst his presurgery left-sided hemiparesis did improve prior to discharge from the neurosurgical unit, he was left with persistent choreiform movements of the left side. The time between injury and neuropsychological review was 1 month. At the time of this neuropsychological review, he was not taking any regular medications. His neuropsychological review confirmed the presence of severe behavioural and mood issues and identified him a highly vulnerable for posttraumatic stress-related concerns going forward. He was started on tetrabenazine for his choreiform movements after the review by neuropsychology.

Discussion

Most patients in this study cohort achieved excellent surgical outcomes, in-line with those in the published paediatric EDH literature.[4,8] However, using surgical markers of good outcomes such as mortality, recurrence, infection and scales such as the raw GOS may not capture more subtle deficits that may affect children following head injuries. The follow-up scheduling for these children has also received comparatively little attention.[1,4]

It is established that paediatric head trauma can lead to neuropsychological issues as the child develops in the

proceeding months or years postinjury.[10–12] Historically, the relationship between head injury and psychological issues had been thought to correlate with the severity of brain injury, and in particular, the degree of frontal intraparenchymal injury; therefore EDH is often considered lower risk for neuropsychological issues versus injuries that involve brain contusions, subdural haematomas or diffuse axonal injury.[6,7] However, more recent work has now established that 30 to 40% of children can be at risk of neuropsychological disturbances after even a mild brain injury, without radiological evidence of intraparenchymal injury.[7,13] However, neuropsychological outcomes following EDH, specifically, are rarely reported.[4,8] The present study was designed to describe existing follow-up regimes for children after EDH surgery and assess whether neuropsychological deficits are being identified at follow-up for these children, and if so, whether such symptoms are being appropriately assessed and treated.

Most patients in this study cohort did receive at least one follow-up review within a median duration of follow-up inline with that reported in previous EDH case series.[2,4] Most children had a single follow-up appointment within the paediatric neurosurgery outpatient clinic, after which they were discharged. Children who had multiple follow-up appointments were more likely to have long-term sequelae, physically and neuropsychologically, than children discharged after one appointment. However, delayed onset of neuropsychiatric symptoms following paediatric head injury, beyond the typical EDH follow-up regimes reported in this study and others, has been described.[10,13] Therefore, it remains possible that some EDH patients are at risk of developing delayed neuropsychological symptoms, which may not be identified if only a single, acute follow-up appointment is arranged. It may be wise to consider both an acute and a later, delayed follow-up review for children after any significant head injury, including EDH, to permit screening for delayed neurocognitive and psychological issues, posttraumatic stress disorder (PTSD) and impaired school performance, which are associated with paediatric head injury.[12]

Forty percent ($n = 12$) of patients who received follow-up in the study cohort had neuropsychological concerns identified. The presence of these symptoms does not seem to be related to confounding factors such as concomitant contusions, skull fractures, seizures or medications (►**Tables 2** and **3**). Of note, there were no patients in the present study who were taking antiseizure medications at the time of their neuropsychological reviews, which are known to be associated with neuropsychological side effects.[5] Only low preoperative GCS, a gross surrogate marker of a more severe overall TBI, was significantly associated with neuropsychological morbidity in this study, which has been widely reported by others.[10,14] This suggests that in children with a low preoperative GCS, EDH in of itself carries a risk of neuropsychological morbidity in children, and so routine screening for these deficits may be important to optimise care for children, even after an isolated EDH. Early intervention for EDH in children with a poor GCS is known to improve surgical outcomes[4]; whether the timing of surgery influences neuropsychological outcomes was not the focus of the present study, but it is likely.[10,12] Of note, half of the children in the present study who had neuropsychological reviews also had a reasonably high preoperative GCS of 14/15 (►**Table 6**). This highlights the potential need for vigilance for neuropsychological issues after surgery for EDH in children, even if their preoperative GCS was not particularly low.

Neuropsychological symptoms are significant issues after TBI and come with marked treatment challenges within the context of paediatrics, but are rarely considered in children who have had an EDH.[3,6,9,10,14] These symptoms can be severely debilitating and progress over time, affecting school performance and social skills development.[10,12] They thus require prompt recognition and subsequent referral for specialist assessment. Two-thirds of the patients who had neuropsychological issues in the present study did not receive neuropsychology reviews and, therefore, received no neuropsychological treatment. This discrepancy may relate to financial constraints, particularly within the context of the coronavirus pandemic, which spanned 2 years of this study's timeline. Furthermore, the departure of our unit's resident paediatric neuropsychologist undoubtedly affected the referral stream to the neuropsychology department. The nature of tertiary services may also influence patient attendance for follow-up and/or neuropsychology reviews; this is especially pertinent in the realm of neurosurgical patients, who are pooled from wide geographical areas. Finally, neuropsychological symptoms can be subtle and difficult for clinicians, parents and school workers to detect without a high index of suspicion.[10,11] It is therefore vital that clinicians are aware that EDH patients are at risk of neuropsychological morbidity, even when their surgical outcomes appear excellent, and that parents and caregivers are appropriately counselled on the neuropsychological symptoms to be vigilant for in the months following EDH surgery.

The implementation of specialist, multidisciplinary paediatric head injury clinics, where financially feasible, may allow streamlining of follow-up and provide a standard framework in which all children receive appropriate access to a neurologist, neurosurgeon and paediatric neuropsychologist following TBI, including postoperatively following an EDH. This would reduce the number of visits to a tertiary care centre for patients who struggle to travel, potentially improving attendance and patient/parent concordance with treatment plans. It may also prove cost-effective, particularly if run in a hybrid fashion, combining virtual and face-to-face follow-ups with multiple specialities as required, on a case-by-case basis. As a result of this study, combined with other data on the need for neuropsychology services in South Wales, more resources have recently been agreed by the Specialist Commissioners for paediatric neuropsychology.

Gross TBI outcome scales, such as the GOS, are typically designed for adult patients. This has led to the development of more detailed neurological and psychological assessments for children who have suffered head injuries, such as the Paediatric GOS-Extended and the King's Outcome Scale for

Childhood Head Injury.[2,15,16] These scales include considerations that are more likely to capture neuropsychological deficits in children post-TBI, such as screening for changes in family/friend relationships, effects on school performance and mood disturbances. However, these scales are rarely used in the EDH literature to assess outcomes.[4,8] Utilising these succinct, paediatric-specific tools at neurosurgical follow-up appointments after EDH could aid clinicians in identifying subtle, yet potentially disabling, neuropsychological issues in these children, who may otherwise appear to be very well. This, in turn, may lead to more holistic paediatric care and rehabilitation after surgery for EDH.

The children within this series of surgically treated EDHs had excellent surgical outcomes. However, this study highlights that follow-up of children following surgery for EDH can be sporadic and neuropsychological reviews may be sparse, despite neuropsychological symptoms developing in 40% of children after their EDH was evacuated. We, therefore, advocate standardising follow-up regimes and consideration of routine neuropsychological review for all children who have surgery for an EDH.

Ethical Approval Statement

This study was performed in line with the principles stated in the Declaration of Helsinki and the approval for the retrospective study was granted by the local South Wales Neuroscience Research and Audit Ethics Committee.

Conflict of Interest

None declared.

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