Pediatric cerebral venous sinus thrombosis or compression in the setting of skull fractures from blunt head trauma

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OBJECTIVE Pediatric cerebral venous sinus thrombosis has been previously described in the setting of blunt head trauma; however, the population demographics, risk factors for thrombosis, and the risks and benefits of detection and treatment in this patient population are poorly defined. Furthermore, few reports differentiate between different forms of sinus pathology. A series of pediatric patients with skull fractures who underwent venous imaging and were diagnosed with intrinsic cerebral venous sinus thrombosis or extrinsic sinus compression is presented.

METHODS The medical records of patients at 2 pediatric trauma centers were retrospectively reviewed. Patients who were evaluated for blunt head trauma from January 2003 to December 2013, diagnosed with a skull fracture, and underwent venous imaging were included.

RESULTS Of 2224 pediatric patients with skull fractures following blunt trauma, 41 patients (2%) underwent venous imaging. Of these, 8 patients (20%) had intrinsic sinus thrombosis and 14 patients (34%) displayed extrinsic compression of a venous sinus. Three patients with intrinsic sinus thrombosis developed venous infarcts, and 2 of these patients were treated with anticoagulation. One patient with extrinsic sinus compression by a depressed skull fracture underwent surgical elevation of the fracture. All patients with sinus pathology were discharged to home or inpatient rehabilitation. Among patients who underwent follow-up imaging, the sinus pathology had resolved by 6 months postinjury in 80% of patients with intrinsic thrombosis as well as 80% of patients with extrinsic compression. All patients with intrinsic thrombosis or extrinsic compression had a Glasgow Outcome Scale score of 4 or 5 at their last follow-up.

CONCLUSIONS In this series of pediatric trauma patients who underwent venous imaging for suspected thrombosis, the yield of detecting intrinsic thrombosis and/or extrinsic compression of a venous sinus was high. However, few patients developed venous hypertension or infarction and were subsequently treated with anticoagulation or surgical decompression of the sinus. Most had spontaneous resolution and good neurological outcomes without treatment. Therefore, in the setting of pediatric skull fractures after blunt injury, venous imaging is recommended when venous hypertension or infarction is suspected and anticoagulation is being considered. However, there is little indication for pervasive venous imaging after pediatric skull fractures, especially in light of the potential risks of CT venography or MR venography in the pediatric population and the unclear benefits of anticoagulation.

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KEY WORDS venous sinus thrombosis; dural sinus thrombosis; anticoagulation; pediatric; trauma; skull fracture

ABBREVIATIONS AHA = American Heart Association; ASA = American Stroke Association; CTV = CT venography; CVST = cerebral venous sinus thrombosis; GCS = Glasgow Coma Scale; GOS = Glasgow Outcome Scale; ICH = intracranial hemorrhage; ICP = intracranial pressure; IQR = interquartile range; MRV = MR venography; MVC = motor vehicle collision.

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CEREBRAL venous sinus thrombosis (CVST) is rare among the pediatric population and occurs at an incidence of 0.67 per 100,000 children per year.^{1,42,50,60} A variety of predisposing factors contribute to the risk of sinus thrombosis, including infection,^{26,28} cancer,³³ dehydration,⁴ and prothrombotic disorders,^{27,37} but trauma remains an underrecognized cause of CVST.^{3,12,22,42,50} Although CVST is found in 4% of patients with penetrating trauma,^{39,53} the relationship between blunt head trauma and sinus thrombosis is less clearly described, particularly for pediatric patients. The literature is limited to several case reports and small case series,^{1,2,5,8,16,17,20,23,24,27,29–31,36–38,40–42,44,45,47,49–56,60,62,63} which often do not differentiate between intrinsic sinus thrombosis and extrinsic sinus compression by an extraaxial hematoma, bone fragment, or air. As a result, guidelines for the diagnosis and treatment of pediatric sinus pathology in the setting of blunt trauma remain unclear.

Recent guidelines by the American Heart Association (AHA) and American Stroke Association (ASA), as well as the European Federation of Neurological Societies, recommend anticoagulation for adults with spontaneous sinus thrombosis as long as there is no contraindication to treatment.^{15,48} Similarly, with regard to pediatric patients, AHA published a scientific statement recommending that anticoagulation be instituted in children with CVST (Class IIa, Level of Evidence C recommendation),⁴⁶ and a recent study showed that the lack of anticoagulation was associated with a higher risk of thrombus propagation, venous infarction, and poor outcome.³⁵ The guidelines specifically state that anticoagulation is recommended for patients with an intracranial hemorrhage (ICH) that results from the sinus thrombosis itself (typically as a result of hemorrhagic transformation of a venous infarct). However, trauma patients often have concomitant hemorrhages that are unrelated to venous sinus thrombosis and are at risk for worsening in the setting of anticoagulation, thereby complicating management decisions.

These issues become particularly relevant in pediatric patients who present with a skull fracture in the vicinity of a venous sinus. In recent years, these patients have undergone an increasingly vigorous workup for CVST. However, CT venography (CTV) involves additional radiation and intravenous contrast, while MR venography (MRV) is a lengthier examination and may require anesthesia. As a result, additional neuroimaging should be used judiciously, namely when the treatment course would be altered by the result of the study. Additional data regarding the incidence, demographics, natural history, and management of pediatric traumatic CVST and/or extrinsic compression will help elucidate which patients will benefit from further workup and treatment. Therefore, we describe our experience with pediatric patients who presented with blunt head trauma and a skull fracture and underwent workup for cerebral venous sinus pathology.

Methods

Patient Population

After obtaining approval from the Johns Hopkins Medicine institutional review board, we retrospectively re-

viewed 2268 consecutive patients with skull fractures who were evaluated at the Johns Hopkins Children's Center and Johns Hopkins All Children's Hospital after sustaining blunt trauma between January 2003 and December 2013 and were entered prospectively into an institutional trauma database. Inclusion criteria were age 18 years or younger, a mechanism of injury involving blunt head trauma, an *International Classification of Diseases, Ninth Revision* (ICD-9) diagnosis code of 800.0 through 804.0, and evaluation of the venous sinuses with CTV, MRV, or digital subtraction angiography. Forty-four patients with penetrating injuries were excluded to minimize confounding variables that may be associated with penetrating head trauma, including increased risk of infection, vascular injury, and direct venous sinus injury. The electronic medical records were then reviewed to identify the subset of patients with venous imaging. Of these 2224 patients, 41 patients (2%) underwent venous imaging. Among this group of 41 patients, 19 patients (46%) had patent venous sinuses, 8 patients (20%) were found to have intrinsic CVST, and 14 patients (34%) demonstrated cerebral venous sinus narrowing as a result of extrinsic compression by an extraaxial hemorrhage, bone fragment, or air. The study group consisted of 28 male and 13 female patients with a mean age at first presentation of 7.5 years (range 1 month to 16 years).

Clinical and Neuroimaging Features

Epidemiological and clinical data were recorded, including age, sex, mechanism of injury, and Glasgow Coma Scale (GCS) score on arrival. Skull fractures were classified by location (i.e., frontal, parietal, temporal, or occipital bones or involving the skull base) and as depressed or nondepressed fractures. Based on the available neuroimaging, venous sinus thromboses were classified by location (i.e., involving the sagittal, transverse, or sigmoid sinus), as occlusive or nonocclusive, and as right or left sided. The presence of concomitant ICH was recorded and classified by the location of the hemorrhage (i.e., subarachnoid, subdural, epidural, intraventricular, or intraparenchymal). Details of the inpatient hospital course were recorded, including length of intensive care unit stay, length of hospital stay, placement of an intracranial pressure (ICP) monitor or external ventricular drain, surgical procedures (i.e., craniotomy or craniectomy), treatment with anticoagulation, and disposition (i.e., home vs rehabilitation). Clinical and neuroimaging outcomes were evaluated by reviewing follow-up clinical notes and reviewing interval imaging to assess sinus recanalization.

Statistical Analysis

Descriptive statistics were reported to summarize the distributions of the clinical features across patient groups (patent venous sinuses, intrinsic sinus thrombosis, and extrinsic sinus compression). Frequency and percentage were used to describe categorical variables, while median and interquartile range (IQR) were reported for continuous variables. The Fisher's exact test was used to compare categorical variables between groups. The Kruskal-Wallis test was applied to compare continuous variables between

TABLE 1. Yield of venous imaging in pediatric patients with skull fractures

Characteristic	Concerning Clinical Exam &/or Intracranial Hypertension	Suspicious Finding on Head CT	Fracture Location &/or Rule Out Vascular Injury	Other	Total Yield
No. of patients	8	7	24	2	41
Patent venous sinuses	4 (50)	3 (43)	10 (42)	2 (100)	19 (46)
Sinus pathology	4 (50)	4 (57)	14 (58)	0 (0)	22 (54)
Intrinsic thrombosis	1 (12)	1 (14)	6 (25)	0 (0)	8 (20)
Extrinsic compression	3 (38)	3 (43)	8 (33)	0 (0)	14 (34)

Values are shown as the number of patients (%).

groups due to the nonparametric distribution of the data. In this study, p values < 0.05 were considered statistically significant.

Results

Yield of Venous Imaging

Of 2224 patients with skull fractures as a result of non-penetrating trauma, 41 patients (2%) underwent venous imaging. Of these, 8 patients (20%) were diagnosed with intrinsic sinus thrombosis, and 14 patients (34%) were diagnosed with extrinsic sinus compression. The indications for venous imaging are summarized in Table 1. Most commonly, the location of the fracture (i.e., adjacent to a venous sinus) was the indication for additional workup with venous imaging in 24 patients, which yielded 6 patients with intrinsic sinus thrombosis and 8 patients with extrinsic sinus compression. The remaining patients typically underwent venous imaging due to poor clinical examination findings that were out of proportion to their imaging findings, intracranial hypertension, or suspicious radiographic findings on a head CT without contrast, such as hyperdensity of the sinus. Regardless of the indication, venous imaging identified similar rates of venous sinus pathology. Either intrinsic sinus thrombosis or extrinsic sinus compression was identified in 50% of the patients who underwent venous imaging due to a concerning clinical examination and/or intracranial hypertension, in 57% of the patients who underwent venous imaging due to a suspicious finding on a head CT without contrast, and in 58% of the patients who underwent venous imaging due to the location of the fracture. Nineteen of 41 patients (46%) underwent venous imaging that did not show any sinus pathology.

Patient Population

The demographic and clinical features of the 41 patients who underwent venous imaging are summarized in Table 2. The majority of patients were male, accounting for 12 patients (63%) with patent sinuses, 5 patients (63%) with intrinsic sinus thrombosis, and 11 patients (79%) with extrinsic sinus compression. The median ages of the patients in each group were similar: patients with patent sinuses had a median age of 9.2 years (IQR 1.4–11.9 years) compared with 6.0 years (IQR 3.3–10.9 years) for patients with intrinsic thrombosis and 7.2 years (IQR 2.4–13.2 years) for patients with extrinsic compression. The most common mechanism of injury in the patients with pat-

ent sinuses or intrinsic sinus thrombosis involved a fall, which accounted for 9 patients (47%) and 4 patients (50%), respectively. Among patients with extrinsic compression, a motor vehicle collision (MVC) was the most common mechanism of injury and occurred in 6 patients (43%), followed by falls, which occurred in 5 patients (36%). Additionally, while injury severity varied between groups, patients with intrinsic sinus thrombosis demonstrated a higher rate of moderate traumatic brain injury, but these differences did not reach statistical significance.

Fracture patterns involved a variety of locations. Overall, patients with extrinsic sinus compression had fractures that most commonly involved the occipital (7 patients [50% of the cohort]) and/or temporal (6 patients [43% of the cohort]) bones. However, patients with intrinsic sinus thrombosis were most likely to have fractures involving the occipital bone (6 patients [75% of the cohort]), whereas temporal bone fractures were less likely (1 patient [13% of the cohort]). Although these differences did not reach statistical significance, there was a trend toward depressed skull fractures and epidural hematomas occurring more commonly in patients with an intrinsic sinus thrombosis or extrinsic sinus compression than in those patients with patent sinuses.

Sinus Pathology

The neuroimaging features and treatment of the 22 patients with intrinsic sinus thrombosis or extrinsic sinus compression are summarized in Table 3. Multiple venous sinuses were involved in 8 patients (36%). Among the 8 patients with intrinsic sinus thrombosis, the thrombus typically involved the transverse or sigmoid sinus, while among the 14 patients with extrinsic sinus compression, the superior sagittal sinus was involved almost as frequently as the transverse and sigmoid sinuses. Five patients (63%) with intrinsic sinus thrombosis demonstrated complete occlusion of the sinus compared with 2 patients (14%) with extrinsic sinus compression ($p = 0.05$).

Venous Infarction and Anticoagulation

Three patients with intrinsic sinus thrombosis were diagnosed with venous infarction or ischemia, and 2 of these patients were treated with anticoagulation. In contrast, none of the patients with extrinsic sinus compression developed a venous infarct ($p = 0.04$). The first patient was a 5-year-old boy who was struck by a bus and underwent an MRV 2 days after presentation due to the

TABLE 2. Demographic and clinical features of pediatric patients with skull fractures

Characteristic	Patent Venous Sinuses	Intrinsic Sinus Thrombosis	Extrinsic Sinus Compression	p Value
No. of patients	19	8	14	
Male sex	12 (63)	5 (63)	11 (79)	0.67
Median age (IQR), yrs	9.2 (1.4–11.9)	6.0 (3.3–10.9)	7.2 (2.4–13.2)	0.96
Mechanism				0.24
Fall	9 (47)	4 (50)	5 (36)	
MVC	1 (5)	1 (13)	6 (43)	
Pedestrian struck	5 (26)	2 (25)	1 (7)	
Nonaccidental trauma	3 (16)	0 (0)	1 (7)	
Other	1 (5)	1 (13)	1 (7)	
Admission GCS score				0.27
3–8	6 (32)	1 (13)	2 (14)	
9–12	3 (16)	4 (50)	2 (14)	
13–15	10 (53)	3 (38)	10 (71)	
Fracture location				
Frontal	5 (26)	1 (13)	3 (21)	0.88
Parietal	8 (42)	1 (13)	4 (29)	0.31
Occipital	8 (42)	6 (75)	7 (50)	0.33
Temporal	11 (58)	1 (13)	6 (43)	0.09
Skull base	5 (26)	3 (38)	4 (29)	0.90
Depressed fractures	2 (11)	2 (25)	6 (43)	0.09
Associated hemorrhage				
Subarachnoid hemorrhage	5 (26)	2 (25)	2 (14)	0.70
Subdural hemorrhage	10 (53)	2 (25)	7 (50)	0.43
Epidural hemorrhage	3 (16)	4 (50)	7 (50)	0.07
Intraparenchymal hemorrhage	8 (42)	4 (50)	6 (43)	1.00
Intraventricular hemorrhage	1 (5)	1 (13)	1 (7)	0.78

Values are shown as the number of patients (%) unless indicated otherwise.

presence of a depressed right occipital fracture adjacent to the transverse sinus (Fig. 1). He was found to have an intrinsic sinus thrombosis causing near-complete occlusion

TABLE 3. Neuroimaging features and treatment of pediatric patients with intrinsic thrombosis or extrinsic compression

Characteristic	Intrinsic Sinus Thrombosis	Extrinsic Sinus Compression	p Value
No. of patients	8	14	
Location			
Superior sagittal sinus	1 (13)	5 (36)	0.35
Transverse sinus	6 (75)	6 (43)	0.20
Sigmoid sinus	6 (75)	6 (43)	0.20
Internal jugular vein	2 (25)	2 (14)	0.60
Occlusive	5 (63)	2 (14)	0.05
Venous infarct	3 (38)	0 (0)	0.04
Anticoagulation	2 (25)	1 (7)*	0.53

Values are shown as the number of patients (%).

* This patient received anticoagulation to treat a concomitant carotid artery dissection rather than venous sinus pathology.

of the right transverse sinus with an associated infarct involving the right temporal and occipital lobes. Despite an initial, transient decline in GCS score, the patient's examination improved spontaneously. He became more alert and did not exhibit any focal neurological deficits. The patient was not treated with anticoagulation due to the concomitant presence of a cerebellar hemorrhage, but he was monitored closely. He was ultimately discharged to inpatient rehabilitation, and on follow-up 4 months later demonstrated spontaneous partial recanalization of the transverse sinus. At his most recent clinical follow-up at 6 years following the injury, he was noted to have made a good recovery and did not have any focal neurological deficits, but he continued to experience posttraumatic stress disorder, anxiety, posttraumatic headaches, and mild learning disabilities.

The second patient with a venous infarct was a 6-year-old girl with Pierre Robin sequence who had an unwitnessed fall at day care and awoke from a nap with left hemiparesis and asymmetrical pupils (Fig. 2). She underwent a head CT, which demonstrated a nondepressed parietal fracture and a right-sided epidural hematoma. The patient underwent an emergency craniotomy and evacuation of the epidural hematoma without complications, but on

FIG. 1. **A:** Axial head CT scan without contrast obtained in a 5-year-old boy who was struck by a bus, showing a depressed right occipital fracture (*arrow*) adjacent to the transverse sinus. **B and C:** Diffusion-weighted MR image (**B**) and matching apparent diffusion coefficient map (**C**) of the brain, showing a venous infarct (*dashed circle*) involving the right temporal and occipital lobes. **D:** MRV showing an intrinsic sinus thrombosis resulting in near-complete occlusion of the right transverse sinus (*arrowheads*). The patient was monitored closely and not treated with anticoagulation. **E:** MRV obtained 4 months later, showing partial recanalization of the right transverse sinus (*arrowheads*).

postoperative day 3 she underwent a head CT for somnolence, which demonstrated an asymmetrical hyperdensity of the right transverse and sigmoid sinuses. The patient subsequently underwent venous imaging, which demonstrated an occlusive thrombus of the right transverse and sigmoid sinuses that extended to the jugular foramen and internal jugular vein, as well as evidence of small venous infarcts involving the right posterior temporal and lateral occipital lobes. She was treated with an intravenous low-dose unfractionated heparin drip, titrated to anti-Xa levels of 0.3–0.5 IU/mL due to her recent craniotomy, and transitioned to subcutaneous enoxaparin for a total of 6 months. Coagulopathy workup was negative. At 6 months after her injury, she had returned to her baseline level of activity with improving left-sided weakness. A follow-up MRV was not completed.

The third patient was a 5-month-old boy who fell from a couch (approximately 2 feet) and was diagnosed with nondepressed occipital and skull base fractures with an adjacent subdural hematoma and subarachnoid hemorrhage (Fig. 3). The patient was intubated due to a declining neurological examination on presentation, and MRI revealed ischemia involving the posterior temporal, occipital, and inferior parietal lobes on the right side, as well as the superior aspect of the right cerebellar hemisphere. A subsequent MRV identified an occlusive thrombus in-

volving the distal superior sagittal sinus, torcula, and right transverse and sigmoid sinuses, which is consistent with the distribution of the ischemic changes. Hypercoagulability workup was negative. The patient was initiated on an intravenous low-dose unfractionated heparin drip at 2 days postinjury. Full-dose anticoagulation was deferred due to the presence of traumatic subarachnoid hemorrhage and a subdural hematoma. On hospital day 15, he was transitioned to enoxaparin with a target anti-Xa level of 0.5–1 IU/mL. After 6 months of treatment, the thrombosis resolved on MRV. At his most recent clinical follow-up at 4.5 years after the injury, the patient was noted to be doing well without neurological deficit.

Surgical Decompression

One patient with extrinsic sinus compression underwent surgical intervention. The patient was an 8-year-old boy who was involved in an MVC. On admission, he was diagnosed with comminuted, depressed, right frontoparietal fractures and frontal lobe contusions (Fig. 4). Due to the location of the fracture, the patient underwent venous imaging, which demonstrated severe compression of the superior sagittal sinus by the depressed calvarial fragments, although the sinus remained patent. The patient underwent a craniotomy for elevation of the depressed skull fractures, and a postoperative CTV demonstrated

FIG. 2. A and B: Three-dimensional surface-shaded CT reconstruction (A) and an axial bone algorithm CT image (B) obtained in a 6-year-old girl who had an unwitnessed fall and developed a nondepressed right parietal fracture (arrow). **C:** Soft-tissue algorithm, non-contrast-enhanced CT image showing an associated right-sided epidural hematoma. **D:** After craniotomy for evacuation of the hematoma, an additional head CT showed an asymmetrical hyperdensity of the right transverse sinus (arrowheads). **E:** MRV showing the complete lack of flow-related enhancement, consistent with an occlusive thrombus of the right transverse and sigmoid sinuses and ipsilateral internal jugular vein (arrowheads). **F and G:** Diffusion-weighted MR image (F) and matching apparent diffusion coefficient map (G) showing a venous infarct (dashed circle). **H:** Interval head CT scan showing stability after the patient was initiated on a low-dose unfractionated heparin drip. Figure is available in color online only.

reexpansion of the superior sagittal sinus. The patient was discharged to home, and at his 3-month follow-up he was neurologically intact. He had returned to school and had no cognitive deficits.

Hospital Course and Disposition

The hospital course, disposition at discharge, and follow-up of the 41 patients who underwent venous imaging are summarized in Table 4. Patients with patent venous sinuses and venous sinus pathology did not have significantly different rates of external ventricular drain or ICP monitor placement. Both patients with patent sinuses and those with venous sinus pathology underwent surgical intervention infrequently, although there was a trend toward a higher craniotomy rate in patients with intrinsic thrombosis. None of the patients in this series underwent shunt placement.

There was a trend toward a longer median length of stay among patients with intrinsic sinus thrombosis (median 11.5 days; IQR 7–21.5 days) than among patients with patent venous sinuses (median 4.0 days; IQR 3–14 days) or extrinsic sinus compression (median 5.0 days; IQR 3–12

days). Anticoagulation was associated with a longer hospitalization (12 and 27 days, respectively, for the 2 patients who were treated with anticoagulation). Of the patients with patent venous sinuses, 14 patients (74%) were discharged to home and 4 patients (21%) were discharged to rehabilitation. One patient died of refractory intracranial hypertension after nonaccidental trauma despite an emergency craniectomy for evacuation of a subdural hematoma. Among the patients with intrinsic sinus thrombosis, 6 patients (75%) were discharged to home and 2 patients (25%) were discharged to rehabilitation, while among the patients with extrinsic sinus compression, 12 patients (86%) were discharged to home and 2 patients (14%) were discharged to rehabilitation. There was no significant difference in disposition between patients with patent venous sinuses and sinus pathology.

Neuroimaging and Clinical Outcomes

Of the 8 patients with intrinsic sinus thrombosis, 5 patients (63%) underwent additional venous imaging following discharge. Among this subset of patients, the thrombo-

FIG. 3. **A:** Axial bone algorithm CT image obtained in a 5-month-old boy who fell from a couch, showing a nondepressed right occipital fracture (*arrow*). **B:** Axial, soft-tissue algorithm, non-contrast-enhanced CT image showing that the fracture was associated with an adjacent subdural hematoma (not shown) and subarachnoid hemorrhage. A large extracranial hematoma was noted overlying the fracture. **C:** Diffusion-weighted MR image showing diffusion restriction involving the posterior temporal, occipital, and inferior parietal lobes (*dashed circle*). **D:** MRV showing an occlusive thrombus involving the distal superior sagittal sinus (*arrowheads*), torcula, and right transverse and sigmoid sinuses. **E:** Follow-up MRV showing recanalization of the sagittal sinus (*arrowheads*) after 6 months of anticoagulation therapy.

FIG. 4. Three-dimensional surface-shaded CT reconstruction (**A**), sagittal multiplanar projection reconstruction CT image (**B**), and sagittal 3D reconstructions of CTV (**C**) showing the comminuted, depressed frontoparietal fractures in an 8-year-old boy involved in an MVC. The superior sagittal sinus was severely compressed by the depressed calvarial fragments. The 3D (**D**) and sagittal (**E**) reconstructions of a postoperative CTV after craniotomy for elevation of the depressed skull fracture fragments show reperfusion of the superior sagittal sinus. Figure is available in color online only.

TABLE 4. Hospital course, neuroimaging, and clinical outcomes of pediatric patients with skull fractures

Characteristic	Patent Venous Sinuses	Intrinsic Thrombosis	Extrinsic Compression	p Value
No. of patients	19	8	14	
ICP monitoring				
External ventricular drain	1 (5)	2 (25)	1 (7)	0.31
ICP monitor	2 (11)	0 (0)	0 (0)	0.68
Surgery				
Craniotomy	0 (0)	2 (25)*	1 (7)†	0.08
Craniectomy	2 (11)	0 (0)	0 (0)	0.68
Shunt	0 (0)	0 (0)	0 (0)	0.90
Median hospital stay (IQR), days	4.0 (3–14)	11.5 (7–21.5)	5.0 (3–12)	0.07
Median ICU stay (IQR), days	4.0 (2–7)	6.5 (2.5–12.5)	2.0 (1.5–4)	0.14
Disposition				0.90
Home	14 (74)	6 (75)	12 (86)	
Rehabilitation	4 (21)	2 (25)	2 (14)	
Death	1 (5)	0 (0)	0 (0)	
Received FU imaging	NA	5 (63)	5 (36)	0.38
Sinus pathology on FU imaging‡				1.00
Resolved by 3 mos	NA	2 (40)	4 (80)	
Resolved btwn 3 & 6 mos	NA	2 (40)	1 (20)	
Persisted >6 mos	NA	1 (20)	0 (0)	
Received clinical FU	13 (72)	7 (88)	12 (86)	0.60
Median FU (IQR), mos§	6.8 (1.3–28.6)	8.8 (1.4–56.2)	1.5 (0.9–5.7)	0.13
GOS score at last FU‡				0.66
1–3	2 (15)	0 (0)	0 (0)	
4–5	11 (85)	5 (100)	10 (100)	

FU = follow-up; NA = not applicable.

Values are shown as the number of patients (%) unless indicated otherwise.

* Both patients underwent craniotomy for evacuation of an epidural hematoma.

† This patient underwent craniotomy for elevation of a depressed skull fracture that was causing extrinsic compression of the superior sagittal sinus.

‡ Patients who were lost to follow-up were excluded from the analysis.

§ Patients who did not undergo repeat venous imaging were excluded from the analysis.

sis resolved by 6 months in 4 of 5 patients, and 1 of these patients was treated with anticoagulation. In the remaining patient, the thrombosis persisted beyond 6 months, although there was a clear improvement in flow over time and the patient remained clinically stable. Of the 2 patients who were treated with anticoagulation for intrinsic sinus thrombosis, 1 demonstrated resolution of the thrombus after 6 months, and follow-up venous imaging was not pursued in the other patient due to particular needs for anesthesia. Of the 14 patients with extrinsic sinus compression, only 5 patients (36%) underwent additional venous imaging following discharge. All 5 patients demonstrated resolution of the compression by 6 months following the injury. There were no significant differences in the time to resolution among the groups.

Thirteen patients (68%) with patent venous sinuses underwent clinical follow-up for a median duration of 6.8 months (IQR 1.3–28.6 months). Similarly, 7 patients (88%) with intrinsic sinus thrombosis underwent clinical follow-up for a median duration of 8.8 months (IQR 1.4–56.2 months). However, patients with extrinsic sinus compression had a relatively short follow-up, and 12 patients (86%)

underwent follow-up for a median duration of 1.5 months (range 0.9–5.7 months). All patients with follow-up after sinus thrombosis or compression demonstrated a Glasgow Outcome Scale (GOS) score of 4–5. Two patients with patent venous sinuses had a GOS score of 1–3 at the most recent follow-up.

Discussion

This case series describes a cohort of pediatric patients who presented with skull fractures following blunt head trauma and underwent neuroimaging with venography to assess cerebral venous sinus pathology. Our study underscores the complexity involved in determining which patients should undergo venous imaging. Of the 2224 patients who presented with skull fractures following blunt trauma, only 41 patients (2%) underwent venous imaging using CTV or MRV. However, among these 41 patients, venous imaging had a high yield in that sinus pathology (either intrinsic thrombosis or extrinsic compression by an extraaxial hemorrhage, bone fragment, or air) was identified in 22 patients (54%).

In our series, venous imaging was obtained for a variety of indications, each of which had a similar yield with regard to identifying venous pathology. In some cases, additional workup was initiated due to suspicious findings on prior CT or MRI. A variety of radiographic signs have been described in the literature, including high density in the region of the cortical veins (i.e., cord sign),^{21,32} dural sinuses (i.e., dense vein sign),⁷ or torcula (i.e., delta sign or dense triangle sign),^{19,50} as well as filling defects in the superior sagittal sinus following the administration of intravenous contrast (i.e., empty delta sign).^{56,59} Eight patients in this study underwent venography because of clinical findings (headaches, nausea, vomiting, or depressed mental status) or intracranial hypertension that was felt to be inconsistent with the patient's imaging. Other reports of pediatric CVST describe similar presentations: children tend to present with 1) signs of intracranial hypertension, such as headache, nausea/vomiting, papilledema, or impaired consciousness; 2) focal neurological deficits; or 3) seizure activity.^{1,22,37,50,51} However, these symptoms are nonspecific, particularly in the setting of traumatic brain injury, and often lead to a delay in diagnosis. When there is adequate collateral venous circulation, or thrombosis occurs in a nondominant sinus, the patient may even be asymptomatic, which requires an even higher index of suspicion.³¹

Historically, therefore, it has often been the presence of a skull fracture close to a venous sinus or an adjacent epidural hematoma that prompts workup for cerebral venous sinus pathology. In our series, this proximity of the fracture to a venous sinus was the most common reason that venous imaging was performed. Although traumatic CVST has been found in the absence of a fracture,^{31,51,52,56,62} various authors have identified a skull fracture overlying a dural venous sinus as an independent risk factor for sinus thrombosis.^{11,31,42,45,56} Delgado Almandoz et al.¹¹ found that among 159 pediatric and adult patients who presented to the emergency department with skull fractures, 57 patients (36%) had positive findings on CTV; all cases of thrombosis occurred in patients whose fracture extended to a dural venous sinus or the jugular bulb (which was the case in 140 of 159 patients).

Additionally, Rivkin et al.⁴⁵ studied 49 adult and 14 pediatric patients who presented with a skull fracture in the setting of blunt trauma. Eighteen of the adult patients and all of the pediatric patients underwent venography, and CVST was identified in all 18 (100%) of the adult patients and 4 (29%) of the pediatric patients. We found similar rates of CVST and identified 8 patients (20%) with venous sinus thrombosis among the 41 pediatric trauma patients with skull fractures who underwent venous imaging. Furthermore, Rivkin et al.⁴⁵ determined that the frequency of venous imaging in patients with skull fractures increased with time: during the final year of the study, 92.1% of patients with skull fractures underwent venous imaging compared with only 40% of patients in the 1st year of the study. Our own experience similarly demonstrates that patients are now more likely to undergo venous imaging than they were at the beginning of our study: two-thirds of the identified patients underwent venous imaging during the second half of the study. However, the benefit of identifying and treating cerebral venous sinus pathology must be

weighed against the risks of additional radiation and iodinated contrast (in the case of CTV) or the possible need for anesthesia (in the case of MRV) in pediatric patients.

To date, the optimal management of a pediatric trauma patient with CVST remains unclear. Current protocols tend to be extrapolated from adult data. In 2010, the European Federation of Neurological Societies released guidelines for the treatment of CVST in adult patients.¹⁵ This was followed by similar guidelines by AHA/ASA in 2011.⁴⁸ Both sets of guidelines recommend treating patients (without a contraindication to anticoagulation) with either intravenous heparin or subcutaneous low-molecular-weight heparin. ICH resulting from sinus thrombosis is not considered a contraindication. However, these guidelines do not specifically address ICH that does not result from sinus thrombosis. The theoretical risk that these hemorrhages could progress secondary to systemic anticoagulation is a particular concern in trauma patients who are diagnosed with sinus thrombosis and a concomitant traumatic ICH.^{11,31,45,60} As a result, Rivkin et al.⁴⁵ chose not to initiate anticoagulation in 84% of their patients who presented with ICH.

Not only do the guidelines fail to address trauma patients, but also there is evidence that pediatric patients with CVST may not have the same natural history as their adult counterparts. Several authors described cases of pediatric posttraumatic sinus thrombosis with good clinical outcomes and high rates of spontaneous recanalization following conservative management.^{23,55,56,62} Therefore, a protocol used by the Children's Stroke Program at the Hospital for Sick Children withholds anticoagulation at the diagnosis of CVST if there is also significant ICH but repeats venous imaging at 5–7 days postdiagnosis. If thrombus propagation is noted, anticoagulation is then initiated.⁶⁰ In their series of 20 pediatric patients with head injury–associated sinus thrombosis, 14 patients underwent anticoagulation safely despite the presence of significant ICH in 13 of these patients. No patient experienced significant progression of ICH, but 3 patients developed minor bleeding complications that required their treatment to be held. Furthermore, all 6 of the patients who did not undergo anticoagulation therapy demonstrated complete resolution of the thrombus, although this may have been related to selection bias, as some of these patients did not undergo anticoagulation therapy precisely because of the small size of the thrombus and the absence of propagation. Others did not receive anticoagulation therapy due to the extensive nature of their hemorrhages.

Consequently, the management of pediatric trauma patients with sinus thrombosis, particularly those with concomitant ICH unrelated to CVST, remains a complex issue that depends on the clinical judgment of the provider and is determined on a case-by-case basis. In our study, all 8 patients with sinus thrombosis were also found to have ICH. Anticoagulation was withheld in 6 of these 8 patients (75%). Of the remaining patients, there were no significant hemorrhagic complications throughout the administration of anticoagulation. As only these 2 of 3 patients with venous infarction from venous thrombosis were treated with anticoagulation, our experience is not conclusive as to whether anticoagulation improves recanalization or over-

all outcome. As it remains unclear whether treatment with anticoagulation is safe or effective, there may be limited value in pursuing venous imaging in this young population, particularly with the added risks of CTV or MRV, when venous infarction is not suspected. In our series, all 3 patients with venous infarction had a change in mental status early in their hospital course. While a decline in the GCS score may have multiple explanations in a child with a skull fracture adjacent to a venous sinus, occlusive sinus thrombosis resulting in venous infarction should remain high on the differential diagnosis and would be a reasonable indication for venous imaging. Our study also demonstrates a trend toward an association between epidural hemorrhage and depressed fractures, which, if confirmed in larger studies, could heighten the suspicion for venous pathology.

The 14 patients with extrinsic cerebral venous sinus compression due to an extraaxial hemorrhage, bone fragment, or air represent a unique subset of patients. Only a handful of prior case reports^{9,10,13,14,25,34,40,43,57,58,61} and small case series^{6,18,63} differentiate these patients from those with intrinsic sinus thrombosis. In our series, all patients except 1 were observed clinically. The remaining patient underwent craniotomy for elevation of a depressed skull fracture that was causing external compression of the superior sagittal sinus. In such a case, however, management with surgical decompression would be indicated with or without additional venous imaging. In general, extrinsic sinus compression may be difficult to discern radiographically from nonocclusive intrinsic thrombosis, and multimodal imaging is sometimes necessary to confirm the diagnosis. Patients with extrinsic sinus compression who are incorrectly diagnosed with CVST and treated with anticoagulation are at risk for expansion of an extraaxial hemorrhage and further compression of the sinus. Cerebral venous sinus occlusion may, in turn, produce venous hypertension and elevated ICP. An alternative option involves surgical decompression of the involved venous sinus by evacuation of a hemorrhage or elevation of a depressed skull fracture depending on the etiology of the extrinsic sinus compression. As such, despite similar presentations, patients with extrinsic sinus compression should be viewed as distinct from their counterparts with CVST.

This study has several limitations. 1) In addition to the inherent limitations of a retrospective study, our case series may also have been affected by a form of selection bias due to the low percentage of overall patients with skull fractures who underwent venous imaging. Although patients underwent venous imaging more frequently during the later years of the study period, it is likely that some patients with traumatic venous sinus pathology, particularly during the early years of the study, were undiagnosed. 2) Our study was likely underpowered with respect to statistical comparisons among the 3 groups. A larger cohort may have produced more statistically significant findings. 3) Due to the retrospective nature of the study, a standardized protocol for imaging pediatric patients with skull fractures was not available, and each situation was considered on a case-by-case basis. Consequently, some patients underwent CTV while others underwent MRV. Although there are advantages and disadvantages to each imaging modal-

ity, differences in sensitivity and specificity may confound the comparison of patients who were diagnosed and underwent radiographic surveillance with different forms of imaging. 4) The wide range in the length of follow-up may have impacted our long-term findings, particularly with regard to patients with extrinsic sinus compression who had a median duration of follow-up of only 1.5 months. Even among the patients with patent venous sinuses or intrinsic sinus thrombosis, although the median duration of follow-up was 6.8 and 8.8 months, respectively, there were patients within each group with inadequate follow-up. To counter these limitations, a prospective study could be performed with standardized imaging and anticoagulation treatment criteria to facilitate more accurate comparisons between groups of patients.

Conclusions

Pediatric trauma patients with skull fractures adjacent to a venous sinus are undergoing venous imaging with increasing frequency. Venography identifies a high rate of venous pathology, but these patients often have concomitant traumatic ICH that complicates their management. Despite the high yield of venous pathology detected with these imaging techniques, treatment with anticoagulation was pursued in only select cases and bears unclear benefit over expectant management without anticoagulation. Therefore, particularly in the pediatric population where the risks of venous imaging are higher, venous imaging is mostly indicated when venous hypertension or infarction is suspected and treatment with anticoagulation or surgical decompression is being considered. In other cases, despite a high yield, our series demonstrates the benign natural history of sinus pathology from blunt trauma and that the risks of imaging may outweigh its benefits. Based on our analysis in light of these uncertainties, we recommend venous imaging if there is suspicion of venous hypertension or infarction on neuroimaging or neurological examination but not to detect sinus pathology without clinical significance. Prospective studies are needed to identify those patients at the highest risk of venous infarction, the optimal timing and modality of imaging, and outcomes according to treatment paradigm.

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Disclosures

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author Contributions

Conception and design: Ahn, Hersh, Jallo. Acquisition of data: Hersh, Shimony, Groves, Tuite, Liu, Garzon-Muvdi. Analysis and interpretation of data: Ahn, Hersh, Shimony, Groves, Tuite, Jallo, Liu, Garzon-Muvdi, Huisman, Felling. Drafting the article: Hersh. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Ahn. Statistical analysis: Kufera. Study supervision: Ahn.

Supplemental Information

Previous Presentations

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