

Posttraumatic complications in pediatric skull fracture: dural sinus thrombosis, arterial dissection, and cerebrospinal fluid leakage

Adedamola Adepoju, MD, and Matthew A. Adamo, MD

Department of Neurosurgery, Albany Medical College, Albany, New York

OBJECTIVE Skull fracture is associated with several intracranial injuries. The object of this study was to determine the rate of fracture associated with venous thrombosis, intracranial arterial dissection (ICAD), and cerebrospinal fluid (CSF) leakage in pediatric patients. Further, the authors aimed to highlight the features of pediatric skull fracture that predict poor neurological outcomes.

METHOD In this retrospective study, the authors evaluated the records of 258 pediatric patients who had incurred a traumatic skull fracture in the period from 2009 to 2015. All the patients had undergone CT imaging, which was used to characterize the type of skull fracture and other important features, including intracranial hemorrhage. Patients with fracture extending to a dural sinus or proximal to major intracranial vessels had undergone vascular imaging to evaluate for venous thrombosis or arterial dissection. Clinical data were also reviewed for patients who had CSF leakage.

RESULTS Two hundred fifty-eight patients had 302 skull fractures, with 11.6% having multiple fractures. Falling was the most common mechanism of injury (52.3%), and the parietal bone was most frequently involved in the fracture (43.4%). Diastatic fracture was associated with increased intracranial hemorrhage ($p < 0.05$). The rate of venous thrombosis was 0.4%, and the rate of ICAD was also 0.4%. The rate of CSF leakage was 2.3%. Skull base fracture was the only significant risk factor associated with an increased risk of CSF leakage ($p < 0.05$). There was a significant difference in fracture-related morbidity in patients younger than versus older than 2 years of age. Patients younger than 2 years had fewer intracranial hemorrhages (21.8% vs 38.8%) and fewer neurosurgical interventions (3.0% vs 12.7%) than the patients older than 2 years ($p < 0.001$). Moreover, skull fracture in the younger group was mostly caused by falling (81.2% vs 33.1%); in the older group, fracture was most often caused by vehicle-related accidents (35.7% vs 4.0%) and being struck by or against an object (19.1% vs 7.9%). Additionally, skull fracture location was analyzed based on the mechanism of injury. Parietal bone fracture was closely associated with falling, and temporal bone fracture was associated with being struck by or against an object ($p < 0.05$). Frontal bone fracture was more associated with being struck by or against an object and vehicle-related injury ($p < 0.05$) than with falling. Vehicle-related accidents and being struck by or against an object, as opposed to falling, were associated with increased surgical intervention (13.3% vs 16.2% vs 3.7%, respectively).

CONCLUSIONS Pediatric skull fracture usually has a benign outcome in patients who fall and are younger than 2 years of age. Poor prognostic factors include diastasis, an age > 2 years, and fracture caused by vehicle-related accidents or being struck by or against an object. In this series, the rates of venous thrombosis and ICAD were low, and the authors do not advocate vascular imaging unless these disease entities are clinically suspected. Patients with skull base fracture should be closely monitored for CSF leakage.

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KEY WORDS pediatric skull fracture; dural sinus thrombosis; arterial dissection; cerebrospinal fluid leak; trauma

SKULL fracture is a common feature of traumatic head injury in the pediatric population (6.2%–10% of cases per year) and is a major cause of morbidity and mortality.^{1,4,8,18} Technological advances in imaging have allowed us to delineate risk factors associated with severe head injury, and skull fracture is an important clinical finding in the evaluation of patients with traumatic

injury.^{2,16,17,22} Pediatric patients, especially neonates, commonly present with skull fracture from either a low-impact injury, such as falling from a low height, or a high-impact injury, such as a vehicle-related accident. Pediatric patients are managed aggressively and sometimes require neurosurgical treatment.^{2,14,15}

Skull fracture is an independent risk factor for the de-

ABBREVIATIONS CSF = cerebrospinal fluid; CTA = CT angiography; GCS = Glasgow Coma Scale; ICAD = intracranial arterial dissection; MRA = MR angiography.

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velopment of intracranial hemorrhage, which can worsen the neurological outcome in patients with traumatic brain injury.^{7,15} In addition to the intracranial hemorrhage, skull fractures can be associated with less commonly identifiable injuries such as venous thrombosis, intracranial arterial dissection (ICAD), and cerebrospinal fluid (CSF) leakage.^{6,9,10,13,19,21,23–25} The occurrence of these injuries has been studied in adult patients but not in pediatric patients. Venous thrombosis and ICAD can worsen neurological outcome with ischemia and hemorrhage, respectively. Cerebrospinal fluid leakage is also a risk factor for posttraumatic meningitis.^{9,11,20} The objectives of this study were to delineate the rate of venous thrombosis, ICAD, and CSF leakage in the pediatric population with skull fracture. In addition, we wanted to determine the factors predictive of a poor neurological outcome in pediatric patients with skull fractures.

Methods

We obtained approval from the institutional review board at Albany Medical College to retrospectively review the records of patients younger than 18 years old who had incurred traumatic skull fracture in the period from July 2009 to August 2015. Patients with traumatic head injury had undergone noncontrast CT scanning as part of the trauma evaluation based on their clinical presentation. The radiological imaging was reviewed by one of three neuroradiologists in the Department of Radiology at our institution, and they provided reports that we used for our study. Patients with skull fracture are immediately evaluated and treated by the neurosurgical team at our institution. This study included patients with linear fracture, depressed fracture (fragments infolded toward the brain), basilar skull fracture, and diastatic fracture. Single fractures extending across sutures into adjacent bones were considered single, rather than multiple, in classification. Venous thrombosis and ICAD were diagnosed with vascular imaging, which mainly consisted of CT angiography (CTA) or MR angiography (MRA). We determined the number of patients who had CSF leakage based on the clinical examination or laboratory study.

Two hundred sixty-four patients qualified for this study, but 4 patients were discharged or transferred to another facility from the emergency department and were not admitted to our institution. There were no clinical data about these patients; thus, they were excluded from our study. The remaining 260 patients were included in this study. We determined the demographics for this group, including the mean age, median age, and sex. We used the Centers for Disease Control and Prevention (CDC) classification to group mechanisms of injury, which includes falls, vehicle-related accidents, being struck by or against an object, assaults, and unknown.¹² Of importance, pedestrian accidents were grouped under the mechanism of being struck by or against an object. We also included in the study sports-related injuries such as those occurring while skiing, sledging, diving, and undertaking other sports activities.

We classified patients based on the number of fractures incurred (single vs multiple), type of fracture, mechanism of injury, fracture sites, presence of intracranial hemorrhage, and Glasgow Coma Scale (GCS) score at the initial

presentation. Single linear fractures that branched from a point into separate linear fractures were classified as multiple fractures. Only patients who had undergone craniotomy or craniectomy were classified as having received neurosurgical treatment. Conservative management consisted of accepted medical therapy, including appropriate administration of anticoagulation or antiplatelet agents or other medical therapies as indicated, as well as intracranial monitoring, external ventricular drainage, or lumbar puncture or drain.

We used the chi-square test to determine statistical significance in our study. A p value < 0.001 was considered significant.

Results

During the study period, 258 patients (60.5% male, 39.5% female) presented with 302 skull fractures (Table 1). The mean age was 6.95 years and the median was 6.0 years. Approximately 39.1% of the patients were younger than 2 years of age. The main mechanism of injury was falling (52.3%), followed by vehicle-related accident (23.3%), being struck by or against an object (14.3%), an assault (4.3%), and sports-related injury (3.9%). We could not account for cause of injury in 1.9% of the patients. Most of the patients had moderate to mild head injury with an initial GCS score > 9 in 89.2%. The majority of skull fractures were linear (84.1%), and depressed fractures occurred in 9.9% of cases. About 6.0% of the cases were diastasis fractures. The parietal bone was the most common fracture site (43.4%), followed by the temporal bone (30.6%) and frontal bone (24.0%). Occipital and skull base fractures occurred in 20.9% and 17.8% of the patients, respectively. About 32.2% of the patients had an intracranial hemorrhage, of which epidural and subdural hematomas were present equally (approximately 14% each). Subarachnoid and intraparenchymal hemorrhages occurred in 11.2% and 7.8% of patients, respectively. The majority of patients (57.1%) had more than one type of intracranial hemorrhage (data not shown).

Thirty patients (11.6%) had more than 1 fracture, with 8 patients in this group having more than 2 fractures. There was no statistical association between mechanism of injury and multiple skull fractures (Table 2). Multiple fractures were associated with increased diastasis (20% vs 5.3%, $p < 0.01$) but not with depressed fracture. Depressed skull fracture was more prominent in the single-fracture group (11.8% vs 10%) but not at a statistically significant level. Multiple fractures were associated with severe head injury as identified by an initial GCS Score 3–8 (30.0% vs 8.3%, $p < 0.05$), but the rate of intracranial hemorrhage was similar in the 2 groups (33.3% vs 32.0%). More patients with multiple fractures required neurosurgical treatment (16.7% vs 7.9%) but there was no statistical difference between the 2 groups. Sixteen patients (6.2%) had diastatic fractures (Table 3), and we compared this group to patients without diastatic fracture. There was no significant association between mechanism of injury and diastatic fracture. Although diastatic fracture was associated with increased intracranial hemorrhage ($p < 0.05$), none of the patients with such fractures required neurosurgical intervention.

TABLE 1. Demographics of patients with skull fractures

Parameter	No.	%
No. of patients	258	
Female	102	39.5
Male	156	60.5
Age in yrs		
Mean	6.95	
Median	6.00	
Mechanism of injury		
Fall	135	52.3
Vehicle related	60	23.2
Struck by or against an object	37	14.3
Assault	11	4.3
Sports related	10	3.9
Unknown	5	1.9
Initial GCS score		
3–8	28	10.8
9–12	20	7.8
13–15	210	81.4
Total fxs	302	
Depressed fx	30	9.9
Linear fx	254	84.1
Diastasis	18	6.0
Patients w/ >1 fx	30	11.6
Fx involving		
Frontal bone	62	24.0
Parietal bone	112	43.4
Temporal bone	79	30.6
Occipital bone	54	20.9
Skull base	46	17.8
Fx involving venous sinus	6	2.3
Pneumocephalus	49	19.0
ICH	83	32.2
Venous thrombosis	1	0.4
Surgical treatment	23	8.9
CSF leakage	6	2.3
Arterial dissection	1	0.4

fx = fracture; ICH = intracranial hemorrhage.

We compared the patients with the 3 most common mechanisms of injury: fall, vehicle related, and struck by or against an object (Table 4). One hundred thirty-five patients had presented with a fall, 60 with a vehicle-related injury, and 37 had been struck by or against an object. Parietal bone fracture was more common in the fall group (52.6%) than in the groups with vehicle-related accidents (38.3%) or those struck by or against an object (27.0%). Conversely, frontal bone fracture was more common in the vehicle-related group (35.0%) and the struck group (29.7%) than in the fall group (18.5%). Temporal bone fracture was most common in the struck group (59.4%). These findings were statistically significant ($p < 0.05$). Severe head injury based on an initial GCS score of 3–8 was more often associated with vehicle-related injury (25.0%

TABLE 2. Comparison of patients with multiple versus single skull fractures

Parameter	>1 Fx		1 Fx		p Value
	No.	%	No.	%	
Total no. of patients	30	11.6	228	88.4	
Mean age in yrs	8.52		6.7		
No. of patients					
Female	12	40.0	90	39.5	
Male	18	60.0	138	60.5	
Mechanism of injury					
Fall	13	43.3	122	53.5	0.294
Vehicle related	9	30.0	55	24.1	0.484
Struck by or against an object	5	16.7	28	12.3	
Assault	1	3.3	10	4.4	
Sports related	2	6.7	8	3.5	
Unknown	0	0.0	5	2.2	
Depressed fx	3	10.0	27	11.8	0.767
Diastasis fx	6	20.0	12	5.3	<0.01
Initial GCS score					
3–8	9	30.0	19	8.3	<0.01
9–12	6	20.0	14	6.1	
13–15	15	50.0	195	85.5	
ICH	10	33.3	73	32.0	0.885
Surgical treatment	5	16.7	18	7.9	0.113

vs 6.7% in the fall group and 5.4% in the struck group, $p < 0.05$). The struck group had a significant increase in intracranial hemorrhage compared with the vehicle-related and fall groups (37.8% vs 10.0% and 4.4%, respectively, $p < 0.05$). The need for neurosurgical treatment was more common in the struck group (16.2%) and vehicle-related group (13.3%) than in the fall group (3.7%; $p < 0.05$). Thus, vehicle-related accidents and being struck by or against an object were associated with intracranial hemorrhage and the need for neurosurgical treatment.

About 40% of the study group was under 2 years of age, and they tended to present with low-impact injuries. We divided the patients into 2 groups according to age— younger than 2 versus older than 2—to determine if there was a difference between the two (Table 5). Falling was the major cause of skull fracture in the group younger than 2 (81.2% vs 33.1%), whereas vehicle-related accidents (35.7% vs 4.0%) and being struck by or against an object (19.1% vs 7.9%) were major causes of injury in the group older than 2 ($p < 0.001$). The younger group had more parietal fractures than the older group (70.3% vs 26.1%). The latter group had more frontal (29.9% vs 14.8%), temporal (36.3% vs 21.8%), and skull base (25.5% vs 5.9%) fractures than the former group ($p < 0.001$). Severe head injury as indicated by an initial GCS Score 3–8 was more common in the older group (15.3% vs 4.0%), as was increased intracranial hemorrhage (38.85% vs 21.78%, $p < 0.001$). Furthermore, the older group had neurosurgical treatment more often than the younger group (12.7% vs 3.0%, $p < 0.001$). In sum, skull fracture in patients older than 2 years

TABLE 3. Comparison of patients with diastatic and nondiastatic skull fractures

Parameter	Diastatic Fx		Nondiastatic Fx		p Value
	No.	%	No.	%	
No. of patients	16	6.2	242	93.8	
Mechanism of injury					
Fall	6	37.5	129	53.3	0.220
Vehicle related	6	37.5	54	22.3	0.164
Struck by or against an object	4	25.0	33	13.6	0.209
Assault	0	0.0	11	4.5	
Sports related	0	0.0	10	4.1	
Unknown	0	0.0	5	2.1	
Initial GCS score					
3–8	3	18.8	25	10.3	0.294
9–12	2	12.5	18	7.4	
13–15	11	68.8	199	82.2	0.180
ICH	9	56.2	74	30.6	0.033
Surgical treatment	0	0.0	0	0.0	
Depressed	0	0.0	30	12.4	

is more frequently associated with severe head injury, increased intracranial hemorrhage, and the need for neurosurgical treatment.

We also looked into 2 unrelated types of vascular injuries in patients with skull fractures: ICAD and venous thrombosis. Six patients had fractures extending to a dural sinus, and 12 patients had fractures that crossed the path of a major intracranial artery (that is, a skull base fracture extending to the petrosal canal involving the internal carotid artery). These patients had vascular imaging (CTA or MRA), and 1 patient each had ICAD and venous thrombosis, resulting in a 0.4% incidence rate for each injury (Table 1). The patient with arterial dissection was a 17-year-old female who had been involved in a pedestrian accident and presented with multiple fractures including skull base fracture. There was no intracranial hemorrhage or ischemia. The other patient with venous thrombosis sustained an injury while falling from a moving vehicle, and he had a linear fracture that extended over the transverse sinus. He had a small extraaxial hemorrhage around the transverse sinus with extensive pneumocephalus tracking from the transverse to sigmoid sinuses. The extraaxial hematoma worsened, and the patient eventually required neurosurgical treatment.

Six patients (2.3%) developed CSF leakage, and 1 of these patients (16.7%) developed posttraumatic meningitis (Table 6). About 80% of the CSF leakage occurred proximal to a fracture site. In one instance, fracture involving the petrous bone was associated with otorrhea and fracture involving the anterior skull base was associated with rhinorrhea. Fifty percent of these patients had skull base fracture, and it was the most significant fracture associated with CSF leakage ($p < 0.05$). Fifty percent had pneumocephalus, which could suggest a possible connection between the intracranial and extracranial space; however, the association between pneumocephalus and CSF leak-

TABLE 4. Analysis of patients with skull fractures based on mechanism of injury

Parameter	Fall		Vehicle-Related Injury		Struck by or Against an Object		p Value
	No.	%	No.	%	No.	%	
Total no. of patients	135	52.3	60	23.3	37	14.3	
Female	60	44.4	15	25.0	16	43.2	
Male	75	55.6	45	75.0	21	56.8	
Age in yrs							
Mean	3.9		12.5		9.1		
SD	4.8		4.6		5.5		
Fx site							
Frontal	25	18.5	21	35.0	11	29.7	<0.05
Parietal	71	52.6	23	38.3	10	27.0	<0.05
Temporal	24	17.8	13	21.7	22	59.4	<0.05
Occipital	31	23.0	17	28.3	5	13.5	
Skull base	19	14.1	16	26.7	8	21.6	
Initial GCS score							
3–8	9	6.7	15	25.0	2	5.4	<0.05
9–12	2	1.5	7	11.7	7	18.9	
13–15	124	91.8	38	63.3	28	75.7	
ICH	6	4.4	6	10.0	14	37.8	<0.05
Surgical treatment	5	3.7	8	13.3	6	16.2	<0.05

age in patients with skull fracture was not statistically significant. As indicated, the rate of posttraumatic meningitis was 16.7% among the patients with CSF leakage. However, the number of patients with meningitis was not adequate to determine the significance of posttraumatic meningitis.

Discussion

This was a retrospective study to determine the rate of ICAD, dural sinus thrombosis, and CSF leakage in pediatric patients with skull fracture. It was a moderately sized study, and our analysis showed that the majority of patients with skull fracture had a good neurological presentation and outcome, with about one-third having an intracranial hemorrhage and less than 10% requiring neurosurgical intervention. Our data support the findings in other studies that have indicated that falling is the most common cause of injury and that the parietal bone is the most common location for skull fracture.^{1,5,12} Our rates of arterial dissection and venous sinus thrombosis were 0.4% each, and the rate of CSF leakage was 2.33%.

Patients younger than 2 years old, who are more likely to present with a low-impact injury, were compared with patients older than 2. There was a significant difference between these two groups. Falling was the major mechanism of injury in the younger group, whereas fracture due to vehicle-related accidents and being struck by or against an object were common in the older group. Similarly, the site of skull fracture was different between the two groups. Parietal bone fracture was prominent in the younger group, while frontal bone, temporal bone, and skull base fractures were common in the older group.

TABLE 5. Comparison of patients older or younger than 2 years

Parameter	Age in Years				p Value
	>2		<2		
	No.	%	No.	%	
No. of patients	157	60.8	101	39.1	
Female	102	65.0	47	46.5	
Male	55	35.0	54	53.5	
Mechanism of injury					
Fall	52	33.1	82	81.2	<0.001
Vehicle related	57	35.7	4	4.0	<0.001
Struck by or against an object	30	19.1	8	7.9	<0.001
Assault	8	4.5	2	2.0	
Sports related	8	5.1	0	0.0	
Unknown	2	1.3	5	5.9	
Initial GCS score					
3–8	24	15.3	4	4.0	<0.001
9–12	17	10.8	2	2.0	
13–15	116	74.5	95	95.0	
Total fxs	189		113		
Depressed fx	17	9.0	13	11.5	<0.001
Linear fx	158	83.6	96	85.8	
Diastasis	14	7.4	4	3.5	<0.001
No. of patients w/ >1 fx	18	11.5	12	11.9	<0.001
Fx site involving					
Frontal	47	29.9	15	14.8	<0.001
Parietal	41	26.1	71	70.3	<0.001
Temporal	57	36.3	22	21.8	<0.001
Occipital	38	24.2	16	15.8	<0.001
Skull base	40	25.5	6	5.9	<0.001
Pneumocephalus	42	26.8	7	6.9	<0.001
Fx involving venous sinus	3	1.9	3	3.0	
ICH	61	38.8	22	21.8	<0.001
Venous thrombosis	1	0.6	0	0.0	
Surgical treatment	20	12.7	3	3.0	<0.001
CSF leakage	6	3.8	0	0.0	
Arterial dissection	1	0.6	0	0.0	

Furthermore, the older patients had a poorer neurological presentation, had a higher rate of intracranial hemorrhage, and required neurosurgical intervention more often. A possible mechanism to explain the differences between the two age groups could be related to differences in the mechanism of injury. Vehicle-related accidents and being struck by or against an object, which were the most common mechanisms of injury in the patients older than 2 years, were associated with increased intracranial hemorrhage and neurosurgical intervention.

Patients can present with multiple skull fractures and diastatic fractures in the setting of high-impact injuries. It is appropriate to assume that these fractures could be associated with an increased risk of intracranial injury. Our data showed that the presence of multiple fractures was associated with a poor neurological presentation but did not increase the risk of intracranial hemorrhage or neurosurgi-

TABLE 6. Analysis of patients with skull fractures associated with CSF leakage

Parameter	No.	%	p Value
Total no. of patients	6		
Age in yrs			
Mean	12.5		
Median	13.0		
Mechanism of injury			
Fall	2	33.3	
Vehicle related	3	50.0	
Struck by or against an object	1	16.7	
Initial GCS score			
3–8	0	0.0	
9–12	1	16.7	
13–15	5	83.3	
Fx involving			
Frontal bone	2	33.3	
Parietal bone	0	0.0	
Temporal bone	0	0.0	
Occipital bone	1	16.7	
Skull base alone	3	50.0	0.02
Diastasis	2	33.3	
Depressed fx	0	0.0	
Pneumocephalus	3	50.0	0.05
Meningitis	1	16.7	

cal treatment, compared with a single skull fracture. On the other hand, a diastatic fracture was associated with a higher incidence of intracranial hemorrhage than a nondiastatic fracture, but the patients with a diastatic fracture did not require surgical intervention. The opening of the suture line probably reduces intracranial pressure and hence minimizes the need for surgical decompression for cerebral edema associated with severe traumatic brain injury.

Our study showed that the rate of skull fracture-associated venous thrombosis or ICAD in pediatric patients was low at 0.4%. No further neurological injury was associated with the dissection. However, we did not have a large enough sample size to determine the significance of neurological deficits associated with traumatic ICAD. Conversely, the rate of venous thrombosis was low, but the patient developed further complications from anticoagulation, which required surgical intervention. Again, the sample size was too small to statistically determine the significance of venous thrombosis, but this study suggests that venous thrombosis could be associated with a worse outcome. A large study would be required to determine the natural history of skull fractures associated with venous thrombosis and to evaluate the best way to manage these patients and optimize clinical outcomes.

The overall rate of CSF leakage was low in our pediatric skull fracture population, compared with the rate in adult patients with skull fracture. Our data showed a 2.3% rate of CSF leakage, which is lower than the 4.6%–11.5% rate in the adult population.^{3,6} It is possible that the adult group sustained more severe injuries compared with the

injuries in the pediatric group. Our rate of posttraumatic meningitis was 16.7%, which was due to delayed CSF leakage. Skull base fracture was the only statistically significant risk factor associated with CSF leakage. The presence of pneumocephalus was associated with an increased rate of CSF leakage, but was not statistically significant. A large study would provide more information about other factors associated with CSF leakage and how pediatric patients should be managed, but our work is a promising step to expand on and improve the treatment of traumatic head injury in pediatric patients.

Conclusions

In sum, skull fractures in pediatric patients are common in the setting of trauma; however, the rate of significant neurological morbidity is low except when the fracture is associated with skull base and diastatic fractures. In addition, fractures caused by vehicle-related accidents or being struck by or against an object are associated with worse outcomes. Further, our series showed that although the rate of ICAD is low, if this injury is suspected based on clinical examination or if a fracture crosses a sinus or the carotid canal, then vessel imaging with CTA or CT venography is appropriate. Further, clinical suspicion should be high for CSF leakage in pediatric patients with skull base fracture.

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Disclosures

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Author Contributions

Conception and design: both authors. Acquisition of data: Adepoju. Analysis and interpretation of data: Adepoju. Drafting the article: Adepoju. Critically revising the article: both authors. Reviewed submitted version of manuscript: Adepoju. Approved the final version of the manuscript on behalf of both authors: Adamo. Statistical analysis: Adepoju. Study supervision: Adamo.

Correspondence

Matthew A. Adamo, Albany Medical Center, Department of Neurosurgery, 47 New Scotland Ave., MC-10, Albany, NY 12208. email: adamom@mail.amc.edu.