Traumatic injury to the posterior fossa: a secondary analysis and description of case series from the NEXUS head injury dataset

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Summary

Background Traumatic brain injuries involving the posterior fossa are rare and case reports indicate they often result in severe outcomes. We seek to describe characteristics and outcomes of traumatic posterior fossa injuries.

Methods We performed a planned secondary analysis of all patients with posterior fossa injuries enrolled in the NEXUS head computed tomography (CT) validation study dataset. The dataset includes prospectively collected data on all patients undergoing non-contrast cranial CT following blunt traumatic head injury from April 2006 to December 2015, at four emergency departments comprising community and university sites, as well as urban, suburban and rural settings in California (Antelope Valley Hospital, San Francisco General Hospital, UCLA Ronald Reagan Medical Center, UCSF Fresno Community Regional Medical Center). We classified each patient into one of three injury patterns: Type I—notable traumatic injuries primarily above the tentorium, with minimal posterior fossa involvement; Type II—notable traumatic injuries both above and within the posterior fossa; and Type III—notable traumatic injuries primarily within the posterior fossa. We extracted demographic data for each patient as well as physician assessments of the NEXUS head CT and Canadian Head CT rule clinical criteria, mechanisms of injury, patient outcomes, and the location and types of intracranial injuries sustained.

Findings Of 11,770 patients in the database, 184 (1.6%) had posterior fossa injuries on CT imaging. Mean age was 55.4 years (standard deviation 22.5 years, range 2–96 years); 131 (71.2%) were males. We identified 63 patients with Type I injuries, 87 with Type II injuries, and 34 Type III injuries. The most common mechanisms of injury were falls (41%), pedestrian vs automobile (15%), and motor vehicle collisions (13%). On presentation most patients had altered mental status (72%), abnormal behavior (53%), or a neurologic deficit (55%). The majority of individuals, 151 (82%), had clinically important injuries and 111 (60%) required neurosurgical intervention. The dispositions for the subjects included 52 deaths (28%), 49 (27%) patients discharged home, and 48 (26%) discharged to rehabilitation facilities. When compared to individuals with Type I and Type II injuries, patients with Type III injuries had lower mortality (6% vs 30% and 35%) and higher percentage of patients discharged home (60% vs 19% and 21%).

Interpretation Patients with Type I and II injury patterns (those that involve both the posterior fossa and supratentorium) experienced high mortality and disability. Patients with Type III injuries (isolated posterior fossa) had a better prognosis.

Funding None.

Keywords: Acute traumatic brain injury; Posterior fossa; Extradural hematoma

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Research in context

Evidence before this study

We searched PubMed and Google Scholar in March 2023, and again during the manuscript revision stage in December 2023, for research reports using search terms "posterior fossa subdural hematoma," "posterior fossa hemorrhage," "posterior fossa hematoma," "posterior fossa trauma, "cerebellar trauma," "cerebellar hemorrhage," "cerebellar hematoma," "brainstem trauma," "brainstem hematoma," and "brainstem hemorrhage." These searches were supplemented with examination of cited references among the identified papers, as well as using PubMed similar article recommendations, and articles citing the included studies. We restricted our search to original research of human subjects that described the acute presentation of patients with blunt traumatic injuries. We excluded single case reports or case series with fewer than 10 subjects, publications without patient clinical data including outcomes (e.g. radiology descriptive series), reports of penetrating trauma, reports of post-surgical complications, hemorrhage due to birth trauma, delayed presentation (>24 h) and reports of spontaneous hemorrhage such as from atrioventricular malformation or aneurysm.

The prevalence of posterior fossa injuries is rare, ranging from 0.4% to 3.3% of all trauma patients and 2.7%–8.3% of patients with an epidural hematoma. The existing evidence is limited to predominantly small retrospective case series from single centers (typically tertiary referral centers), and subject to selection bias (only examining cases that underwent surgical decompression, or isolated, neurologically intact cases managed conservatively), or focused only on specific injuries, predominantly posterior fossa epidural hematomas. There is considerable variability in the reported signs and symptoms on presentation, interventions, and outcomes. Thus there is a gap in the literature describing the natural spectrum of injuries, prevalence of specific injury types, and overall epidemiology of posterior fossa injuries. Importantly, the articles do not consistently report on the presence of additional intracranial injuries and their impact on management and outcomes.

Added value of this study

The findings of our prospective multisite, observational study of individuals experiencing blunt traumatic head injury add to our understanding of this rare type of injury by including a description of all traumatic injuries noted on CT imaging in patients suffering traumatic injury to the posterior fossa. Our data provide a comprehensive description of the spectrum of injuries among this cohort. We also report the overall prevalence of posterior fossa injuries as well as the prevalence of various subtypes of injuries and associated demographics, presentations and outcomes among all patients presenting to emergency departments with head injuries. Our stratification of cases based on the patterns of injury is a novel approach to considering these cases, and highlights the importance of supratentorial injuries in determining clinical outcomes.

Implications of all the available evidence

Our findings in this descriptive report confirm that injuries to the posterior fossa are indeed rare, and typically occur as part of a larger injury pattern that frequently involves extensive supratentorial injuries. Our data address conflicting reports on clinical outcomes for patients suffering these injuries, indicating that morbidity and mortality are markedly increased among patients sustaining significant injuries above the tentorium, while patients with minimal or no supratentorial injuries noted on CT scan experience significantly lower morbidity and mortality.

Clinical outcomes primarily depend on the presence and extent of supratentorial injury, while isolated posterior fossa injuries are generally associated with favorable outcomes. Our findings will enable clinicians to better recognize the spectrum of posterior fossa injuries and the importance of other intracranial injuries, and will consequently enable them to make more informed decisions regarding triage, resource utilization, and outcomes. Future research should focus on further stratification of these injuries to better define the optimal management of specific types of injuries, with consideration given to whether these injuries occur in isolation, or in conjunction with other intracranial injuries.

Introduction

Traumatic injury to the posterior fossa is a rare and potentially life-threatening emergency occurring in approximately 3.3%[1] of the 1.5–2 million cases of traumatic brain injury (TBI) in the United States each year.[2] While the posterior fossa is the largest of the three brain fossae (anterior, middle, and posterior), it has the lowest threshold for expansion.[3,4] Any increase in volume can quickly generate elevated intracranial pressure, brainstem compression, uncal and tonsillar herniations, and death.[4] Consequently, injuries to the posterior fossa often lead to significant morbidity and mortality.

Due to the rarity and heterogeneity of posterior fossa injuries, there is limited knowledge regarding the epidemiology, injury patterns and outcomes associated with this brain trauma. The current literature mainly consists of small retrospective case studies or case series limited to specific injuries, such as traumatic posterior fossa subdural, epidural, or cerebellar hematomas.[1,4–20] There is a great deal of variability in the reports of outcomes for these subjects. In this study, we utilize a large case series of blunt trauma patients who received head computed tomography (CT) to provide more robust data on these infrequent injuries. Our aims are to describe the demographics, mechanisms of injury, clinical signs and symptoms, injury patterns, and outcomes of patients who sustain blunt posterior fossa injuries.

Methods

Study design and setting

We performed a secondary analysis of the National Emergency X-radiography Utilization Study (NEXUS) Head CT imaging validation data set.[21] The original multicenter observational study focused on validating the previously derived NEXUS Head CT decision instrument. Our current study represents a preplanned assessment of patients who were found to have injuries involving the posterior fossa. We adhere to STROBE reporting guidelines (STROBE Checklist provided in the supplementary material).[22]

In brief, the NEXUS head CT clinical decision instrument validation was a multicenter, observational case series of emergency department patients receiving non-contrast cranial computed tomography following blunt traumatic head injury from April 2006 to December 2015. The study was conducted in four emergency departments (EDs) in the United States of America, comprising community and university sites, as well as urban, suburban and rural settings (Antelope Valley Hospital in Lancaster, California, San Francisco General Hospital in San Francisco, California, UCLA Ronald Reagan Medical Center in Los Angeles, California, UCSF Fresno Community Regional Medical Center in Fresno, California). We obtained Institutional Review Board approval and waiver from informed consent from University of California, Los Angeles (UCLA) Committee on Human Research for UCLA and UCSF, and separate approvals and waivers from the Antelope Valley Hospital and UCSF Fresno Community Regional Medical Center Institutional Review Boards.

Selection of participants

For the NEXUS validation study, we enrolled blunt head injury patients (all ages) who underwent CT imaging at the participating center and excluded patients presenting with penetrating trauma, delayed presentations greater than 24 h post-injury, and transfers with known intracranial injuries. Enrollment occurred when the treating physician elected to obtain CT head imaging. Under the study protocol, clinicians were required to complete a detailed clinical assessment before CT imaging would occur. Clinicians were able to waive assessments in unstable patients where even a minimal delay could compromise care. These patients were marked as "unstable," and classified as "high risk" by the decision instrument. For the NEXUS decision instrument validation, we included all patients in whom the treating clinician indicated trauma was the reason for obtaining the study. This would include patients with any blunt trauma, including an isolated fall, isolated head injury, found down with signs of head trauma, as well as trauma activations. All patients underwent non-contrast axial scanning from skull base to vertex using a variety of third generation or better computed tomographic scanners, with reconstructions created in the axial, coronal and sagittal planes.

For this secondary analysis we included all patients with any posterior fossa injury identified on CT imaging. To identify eligible patients, we reviewed our detailed listing of the presence and location of all of the individual injuries evident on initial CT imaging for all patients in the original NEXUS validation sample. Discrepancies in injury identification and classification were resolved by third party review. From this listing, we identified all injuries that involved structures in the posterior fossa, including the cerebellum, pons, brainstem, medulla, and fourth ventricle, as well as injuries to immediately adjacent bone and dural structures. Our final sample for this analysis consisted of all patients who exhibited one or more posterior fossa injuries.

Methods of measurement

As described previously,[21] physicians at participating emergency departments (EDs) prospectively collected data during their initial patient assessments on patient demographics, and presenting signs and symptoms (coded yes, no, unknown) including variables incorporated in the NEXUS and Canadian Head CT rules.[23] We collected patient disposition data and head CT imaging data (types of injuries, location, laterality) using standardized chart review methods.[24] We utilized a structured abstraction form, explicit definitions and coding rules (including instructions for missing or conflicting data), two independent trained abstractors with third party resolution of disparities, and independent review of abstraction with a subset of cases for assessment of inter-rater reliability. We used previously defined criteria to classify severity of injury as clinically important or clinically insignificant, and define the need for neurosurgical intervention.[23,25] Key definitions are provided in Table 1.

We stratified the posterior fossa injury cases into three patterns, based on the extent of trauma located above the tentortium and in the posterior fossa on CT scan (Table 1). While Type I and Type II injury patterns are important, the primary focus of our analysis for this study was the Type III injury pattern where existing reports are sparse.

Outcome measures

The primary outcome was the morbidity and mortality of the posterior fossa injuries. As with prior descriptions of NEXUS validation data[21] we characterize injury severity in two ways, reporting clinically important injury and neurosurgical interventions based on the definitions by Stiell et al.[23] (Table 1). Secondary outcomes included the patient's disposition—death, discharge home, transfer to

Pattern of posterior fossa injury as identified on CT imaging:
Type I—Notable traumatic head injuries located above the tentorium and only insignificant or minimal traumatic injuries in the posterior fossa.
Type II—Notable traumatic head injuries located both above the tentorium and within the posterior fossa.
Type III—Notable traumatic head injuries located within the posterior fossa with only insignificant or minimal injuries outside the posterior fossa.
Classification of outcomes. Definition of clinically Important brain injury and neurosurgical intervention is based on work by Stiell et al.[23]**:**
Clinically important head injury: Any acute traumatic brain finding on CT that would normally require hospital admission and neurosurgical follow-up. All CT identified brain injuries are considered important unless the patient is neurologically intact patient and has a one of the following lesions: solitary contusion less than 5 mm in diameter, localized subarachnoid hemorrhage less than 1 mm thick, thin (smear) subdural hematoma less than 4 mm thick, isolated pneumocephaly, or closed depressed skull fractures that does not violate the inner table.
Neurosurgical intervention: defined as death due to head injury, need for craniotomy, elevation of skull fracture, intubation related to head injury, or intracranial pressure monitoring within 7 days of head injury.
Description of posterior fossa injury patterns and clinical outcome categories.

Table 1: **Key definitions.**

another hospital, discharge to rehabilitation center, and leaving against medical advice.

Primary analysis

The original NEXUS head CT decision instrument validation study was designed to provide a high precision (lower limit of 95% confidence interval of 99.0%) for sensitivity and NPV for clinically important injuries. The overall prevalence of any injury in the NEXUS head CT validation set was 11.5% (1352/11,770); 6.5% (767/11,770) with clinically important injury, and 3.6% (420/11,770) with injuries requiring intervention.[21] This current analysis is a post-hoc planned subgroup analysis to share descriptive epidemiology and no sample size was calculated. We provide frequencies and proportions, summary estimates (median (IQR), for the demographics, clinical characteristics and patient outcomes. We note missing data in our summaries and did not impute any values. We assessed inter-rater agreement using both raw agreement (percentage of cases where raters provided identical ratings) and intraclass correlation coefficients (ICC) employing two-way mixed-effects models with single raters and absolute agreement for data abstraction of head CT findings and classification of injuries, types of injuries, location of injuries, and posterior fossa injuries using 100 randomly selected rating pairs for each abstraction. We collected data in REDCap (Research Electronic Data Capture)[26,27] and performed analysis using Excel (v 16.79.2 Microsoft Corporation, Redmond, Washington) and STATA 14 (StataCorp, College Station, Texas).

Role of the funding source

This observational study was not funded, and thus there is no role of any funder in the design, data collection, data analysis, interpretation, or writing of this report.

Results

Enrollment and demographics

The NEXUS validation study enrolled 11,770 blunt head injury patients, including 1352 who exhibited any evidence of cranial or intracranial injury. Among these 1352 individuals, 767 (56.7%) had clinically important injuries, and 420 (31.0%) required neurosurgical intervention. From among the entire NEXUS validation sample, 1.6% (184/11,770) exhibited one or more injuries in posterior fossa and are included in the current descriptive analysis. These patients represent 13.6% of all injured patients (184/1352). This posterior fossa injury subgroup included 131 (71.2%) males. The majority of patients were white 105 (57%), and had an average age of 55.4 years (Standard deviation (SD) = 22.5 years; range 2–96 years). The most common mechanism of injury (40 cases (21.7%)) was fall from a height. Presenting demographics and injury mechanisms are detailed further in Table 2.

Injury severity and distribution of type of injuries

Among the 184 patients with posterior fossa injuries, 151 (82.1%) patients had a clinically important injury and 110 (59.8%) required neurosurgical intervention. This is a higher proportion of both clinically important injury and intervention than is noted in the entire NEXUS validation sample. We identified 63 patients with a Type I injury pattern, 87 with a Type II pattern, and 34 with Type III injuries. Overall, we identified 747 unique traumatic CT findings among the 184 patients with posterior fossa injuries (median 4 [IQR 2, 5; Range 1–14]). These findings include 45 (24.4%) instances of notable shift of intracranial structures, 20 (9.2%) cases exhibiting herniation, and 28 (15.2%) cases with pneumocephalus. The details of the CT abnormalities, stratified by injury type are reported in Table 3. Subdural, subarachnoid and parenchymal hemorrhage were the most common injuries noted overall. The predominant traumatic injury noted within the posterior fossa was subarachnoid hemorrhage. Supplementary Table S1 presents the prevalence of clinically important injuries and need for intervention among the patients presenting with isolated posterior fossa injuries (Type III injury pattern).

Clinical presentation (signs and symptoms, mechanism of injury)

The most prevalent clinical sign of injury in the 184 patients was an abnormal Glasgow Coma Scale (GCS), noted in 135 (73.4%) individuals. However, this clinical finding was present in only 17 of the 34 patients (50.0%) with isolated posterior fossa injuries (Type III). Table 4 provides information on the frequency of presenting

	All patients N (%) N = 184	Type I posterior fossa injury N (%) N = 63	Type II posterior fossa injury N (%) N = 87	Type III posterior fossa injury N (%) N = 34
Age (years)				
Mean	55.4	58.5	55.4	49.8
Standard deviation	22.5	21.6	21.8	25.0
Range	2, 96	4, 91	6, 96	2, 93
Sex:				
Male	131 (71.2)	40 (63.5)	63 (72.4)	28 (82.4)
Female	51 (27.7)	22 (34.9)	23 (26.4)	6 (17.6)
Unknown	2 (1.1)	1 (1.6)	1 (1.1)	0
Ethnicity				
Hispanic	42 (22.8)	12 (19.0)	18 (20.7)	12 (35.3)
Non-Hispanic	141 (76.6)	51 (81)	68 (78.2)	22 (64.7)
Unknown	1 (0.5)	0 (0)	1 (1.1)	0 (0)
Race				
Asian	12 (6.5)	7 (11.1)	4 (4.6)	1 (2.9)
Black	8 (4.3)	3 (4.8)	5 (5.7)	0
Middle eastern	2 (1.1)	2 (3.2)	0	0
Native American	0	0	0	0
White	148 (80.4)	47 (74.6)	69 (79.3)	32 (94.1)
Other	13 (7.1)	4 (6.3)	8 (9.2)	1 (2.9)
Unknown	1 (0.5)	0	1 (1.1)	0
Mechanism of injury				
Assault	6 (3.3)	2 (3.2)	1 (1.1)	3 (8.8)
Bicycle	21 (11.4)	11 (17.4)	8 (9.2)	2 (5.9)
Dive injury	1 (0.5)	1 (1.6)	0	0
Fall–Ground level	35 (19.0)	15 (23.8)	15 (17.2)	5 (14.7)
Fall from height	40 (21.7)	10 (15.9)	20 (23.0)	10 (29.4)
Found down	1 (0.5)	0	0	1 (2.9)
Motor vehicle collision	23 (12.5)	4 (6.3)	16 (18.4)	3 (8.8)
Motorcycle collision	15 (8.2)	3 (4.8)	8 (9.2)	4 (11.8)
Pedestrian vs auto	28 (15.2)	12 (19.0)	12 (13.8)	4 (11.8)
Skateboard	1 (0.5)	0	1 (1.1)	0
Unknown	13 (7.1)	5 (7.9)	6 (6.9)	2 (5.9)

Table 2: **Demographics and mechanism of injury by type of posterior fossa injury.**

signs and symptoms for Type I, II, and III posterior fossa categories. We observed clinical evidence of a basilar or depressed skull fracture in 42 patients, 41 of whom were classified as having sustained clinically important injuries, yielding a positive predictive value of 97.6% for this sign. We documented neurological deficits in 101 patients, including 81 (80.2%) who required neurosurgical intervention, making this the most significant single criterion in predicting the need for intervention. Details of the frequency of presenting signs and symptoms and clinical outcome severity are reported in Table 4.

Clinical outcomes/disposition

We were able to obtain final discharge destination for 164 (89.1%) patients. For the other 11% of cases, we could not definitively determine whether they were discharged home or to a rehabilitation facility from our review of the hospital discharge and social worker notes. Overall, we observed a case fatality rate of 28.3% (52 of 184 patients), and a discharge to home rate of 26.1% (49 of 184 patients). The highest mortality rate 47.3% (52 of 110 patients) occurred among patients requiring neurosurgical intervention. Patients with isolated posterior fossa injuries (Type III cases) had the lowest mortality rate 5.9% (2 of 34 patients) and the highest rate of discharge to home (55.9% or 19 of 32 patients). Table 5 outlines the outcome dispositions for the study sample. Mortality among patients experiencing subfalcine and parafalcine herniations was 50% (5 of 10), and 66.7% (8 of 12) among patients with uncal herniations. Mortality was 100% (3 of 3) among those experiencing tonsillar herniations.

Technical assessment of classification and injury ratings

Clinicians designated 49 patients as unstable, but were able to provide nearly complete assessments on 47

	All patients N (%) N = 184	Pattern of posterior fossa injury			Clinical outcomes	
		Type I N (%) N = 63	Type II N (%) N = 87	Type III N (%) N = 34	Clinically important injury N (%) N = 151	Neurosurgical intervention N (%) N = 110
Edema	28	12	13	3	28	26
Diffuse axonal injury	5	1	4	0	5	5
Pneumocephalus	28	11	15	2	27	22
Herniation:	20	9	11	0	19	18
Subfalcine/Parafalcine	10	3	7	0	10	10
Tentorial	14	8	6	0	14	13
Tonsillar	3	1	2	0	3	3
Skull fractures						
Nondisplaced skull fracture	70	24	41	5	67	51
Displaced/Diastatic skull fracture	19	8	10	1	19	17
Depressed skull fracture	5	2	2	1	5	3
Basilar skull fracture	55	14	37	4	55	45
Hemorrhage—Supratentorial						
Contusion/Petechial hemorrhage	94	38	44	12	76	64
Parenchymal hemorrhage	129	50	71	8	119	97
Subdural hematoma	12	4	7	1	11	8
Epidural hematoma	15	2	12	1	13	9
Extra-Axial hemorrhage	20	2	14	4	15	0
Subarachnoid	37	14	21	2	36	28
IVH	2	1	1	0	2	2
Hemorrhage posterior fossa						
Contusion/Petechial hemorrhage	10	2	6	2	6	0
Parenchymal hemorrhage	27	6	16	5	25	19
Subdural hematoma	20	7	9	4	18	12
Epidural hematoma	5	0	4	1	5	1
Extra-Axial hemorrhage	6	0	4	2	2	2
Subarachnoid	159	65	73	21	135	103
Intraventricular hemorrhage	0	0	0	0	0	0

[a]Note: This table presents all injuries, a single individual may have had multiple injuries of the same type.

Table 3: **Intracranial injuries among blunt head injury patients with posterior fossa injuries.**[a]

(96%) of these cases (they were unable to provide assessment of coagulopathy on 35 cases with altered mental status). Missing assessments for the full sample are documented in Table 4 as "unknown."

Our raw inter-rater agreement on number of injuries was 90% (95% Confidence Interval (CI); 82.4%–95.1%), ICC 0.94 (95% CI; 0.91–0.96); raw agreement on type of injuries was 93% (95% CI; 86.1%–97.1%), ICC 0.88 (95% CI; 0.83–0.92); raw agreement on the location of injuries was 92% (95% CI; 84.8%–96.5%, ICC 0.90 (95% CI; 0.85%–0.93%); raw agreement on the classification of posterior fossa injury was 94% (95% CI; 89.4–96.9), ICC 0.94 (95% CI; 0.92–0.96).

Discussion

In this large, multicenter, observational case series of patients with posterior fossa injuries, we provide greater characterization of the presentation, injuries, and patient outcomes than prior case series and reports.[1,4–10,16,19,20] Posterior fossa injuries were uncommon, noted in only 2% of our overall large sample of patients presenting with head trauma. While only 2% of the entire NEXUS validation sample, these cases represented 13.6% of the 1352 patients with traumatic CT findings. The subgroup of patients with posterior fossa injuries more frequently had clinically important injuries (151/184 (82.1%)) as compared to the overall NEXUS validation set injured cases (767/1352 (56.7%)), and required neurosurgical intervention more often (110/184 (59.8%)) than the entire NEXUS validation set (420/1352 (31.0%)). Contrary to prior literature suggesting these injuries are almost always devastating, we found that is not always the case, and a more nuanced consideration of the overall injury pattern provides some distinctions among patients.

We found several types of injuries in the posterior fossa, with subarachnoid hemorrhage, parenchymal hemorrhage and subdural hematomas being most commonly noted. In our series, patients with Type I and Type II injury patterns (predominantly supratentorial

	All patients N (%) N = 184	Pattern of posterior fossa injury			Clinical outcome	
		Type I N (%) N = 63	Type II N (%) N = 87	Type III N (%) N = 34	Clinically important injury N (%) N = 151	Neurosurgical intervention N (%) N = 110
Signs of Basilar/ Depressed skull fracture	Yes = 42 (22.8)	Yes = 19 (30.2)	Yes = 21 (24.1)	Yes = 2 (5.9)	Yes = 41 (27.2)	Yes = 32 (29.1)
	No = 133 (72.3)	No = 41 (65.1)	No = 60 (69.0)	No = 32 (94.1)	No = 101 (66.9)	No = 70 (63.6)
	Unknown = 9 (4.9)	Unknown = 3 (1.6)	Unknown = 6 (6.9)	Unknown = 0 (0.0)	Unknown = 9 (6.0)	Unknown = 8 (7.3)
Scalp hematoma	Yes = 93 (50.5)	Yes = 35 (55.6)	Yes = 43 (49.4)	Yes = 15 (44.1)	Yes = 83 (55.0)	Yes = 61 (55.5)
	No = 80 (43.5)	No = 23 (36.5)	No = 38 (43.7)	No = 19 (55.9)	No = 57 (37.7)	No = 41 (37.3)
	Unknown = 11 (6.0)	Unknown = 5 (7.9)	Unknown = 6 (6.9)	Unknown = 0 (0.0)	Unknown = 11 (7.3)	Unknown = 8 (7.3)
Abnormal level of alertness	Yes - 133 (72.3)	Yes = 50 (79.4)	Yes = 69 (79.3)	Yes = 14 (41.2)	Yes = 123 (81.4)	Yes = 98 (89.1)
	No = 46 (25)	No = 9 (14.3)	No = 17 (19.5)	No = 20 (58.8)	No = 23 (15.2)	No = 8 (7.3)
	Unknown = 5 (2.7)	Unknown = 4 (6.3)	Unknown = 1 (1.1)	Unknown = 0 (0.0)	Unknown = 5 (3.3)	Unknown = 4 (3.6)
Recurrent/Forceful vomiting	Yes = 19 (10.3)	Yes = 7 (11.1)	Yes = 9 (10.3)	Yes = 3 (8.8)	Yes = 18 (11.9)	Yes = 14 (12.7)
	No = 158 (85.9)	No = 53 (84.1)	No = 74 (85.1)	No = 31 (91.2)	No = 126 (83.4)	No = 92 (83.6)
	Unknown = 7 (3.8)	No = 3 (4.8)	Unknown = 4 (4.6)	Unknown = 0 (0.0)	No = 7 (4.6)	Unknown = 4 (3.6)
Abnormal Glasgow Coma Scale (GCS)	Yes = 135 (73.4)	Yes = 52 (82.5)	Yes = 66 (75.9)	Yes = 17 (50.0)	Yes = 121 (90.1)	Yes = 97 (88.2)
	No = 49 (26.6)	No = 11 (17.5)	No = 21 (24.1)	No = 17 (50.0)	No = 30 (19.9)	No = 13 (11.8)
	Unknown = 0 (0.0)	Unknown = 0 (0.0)	Unknown = 0 (0.0)	Unknown = 0 (0.0)	Unknown = 0 (0.0)	Unknown = 0 (0.0)
Abnormal behavior	Yes = 97 (52.7)	Yes = 37 (58.7)	Yes = 46 (52.9)	Yes = 14 (41.2)	Yes = 89 (58.9)	Yes = 68 (61.8)
	No = 73 (39.7)	No = 21 (33.3)	No = 34 (39.1)	No = 18 (52.9)	No = 50 (33.1)	No = 31 (28.2)
	Unknown = 14 (7.6)	Unknown = 5 (7.9)	Unknown 7 (8.0)	Unknown = 2 (5.9)	Unknown = 12 (7.9)	Unknown = 11 (10.0)
Neurologic deficit	Yes = 101 (54.9)	Yes = 42 (66.7)	Yes = 49 (56.3)	Yes = 10 (29.4)	Yes = 97 (64.2)	Yes = 81 (73.6)
	No = 70 (38.0)	No = 16 (25.4)	No = 32 (36.8)	No = 22 (64.7)	No = 42 (27.8)	No = 20 (18.2)
	Unknown = 13 (7.1)	Unknown = 5 (7.9)	Unknown = 6 (6.9)	Unknown = 2 (5.9)	Unknown = 12 (7.9)	Unknown = 9 (8.2)
Coagulopathy	Yes = 13 (7.1)	Yes = 4 (6.3)	Yes = 5 (5.7)	Yes = 4 (11.8)	Yes = 10 (6.6)	Yes = 7 (6.4)
Warfarin	4 (2.2)	2 (3.2)	2 (2.3)	0 (0.0)	4 (2.6)	3 (2.7)
Aspirin	4 (2.2)	0 (0.0)	2 (2.3)	2 (5.9)	3 (2.0)	0 (0.0)
Clopidogrel	5 (2.7)	2 (3.2)	1 (1.1)	2 (5.9)	4 (2.6)	3 (2.7)
	No = 83 (45.1)	No = 26 (41.3)	No = 39 (44.8)	No = 18 (52.9)	No = 63 (41.7)	No = 38 (34.5)
	Unknown = 88 (47.8)	Unknown = 33 (52.4)	Unknown = 43 (49.5)	Unknown = 11 (12.6)	Unknown = 78 (51.7)	Unknown = 65 (59.1)
Amnesia >30 min	Yes = 34 (18.5)	Yes = 14 (22.2)	Yes = 15 (17.2)	Yes = 5 (14.7)	Yes = 25 (16.6)	Yes = 17 (15.5)
	No = 60 (32.7)	No = 20 (31.7)	No = 27 (31.0)	No = 13 (38.2)	No = 45 (29.8)	No = 28 (25.5)
	Unknown = 90 (48.9)	Unknown = 29 (46.0)	Unknown = 45 (51.7)	Unknown = 16 (47.1)	Unknown = 81 (53.6)	Unknown = 65 (59.1)
Dangerous mechanism	Yes = 132 (71.7)	Yes = 48 (76.2)	Yes = 60 (69.0)	Yes = 24 (70.6)	Yes 105 (69.5)	Yes = 81 (73.6)
	No = 28 (15.2)	No = 8 (12.7)	No = 15 (17.2)	No = 5 (14.7)	No = 24 (15.9)	No = 14 (12.7)
	Unknown = 24 (13.0)	Unknown = 7 (11.1)	Unknown = 12 (13.8)	Unknown = 5 (14.7)	Unknown = 17 (11.3)	Unknown = 15 (13.6)

Table 4: **Clinical findings by pattern of posterior fossa injury and by clinical outcome.**

and minimal posterior fossa injuries, or significant supratentorial and posterior fossa injuries) had worse clinical outcomes than those with a Type III injury pattern (predominantly or isolated posterior fossa injuries). Not unexpectedly, patients requiring neurosurgical intervention had a higher mortality. In contrast to what has been reported to portend a poor outcome, we noted unexpectedly relatively better outcomes overall for patients with isolated posterior fossa injuries—lower mortality, high rate of discharge to home and an absence of brain herniation. In fact, and unsurprisingly, in most cases the clinical outcomes were predominantly determined by the extent of the supratentorial injuries as smaller case series have suggested.[4,7,9] This makes sense mechanistically as it is difficult to directly injure the posterior fossa, while the supratentorial areas are more vulnerable. The low death rate and large proportion of patients discharged home with isolated posterior fossa injuries has not been noted previously.

Consistent with prior reports,[4–20] we found that the mechanism of injury most commonly was falls, with similar frequency of high energy (fall from height) and ground level falls. Motor vehicle, bicycle and motorcycle injuries were also common. We found a dangerous mechanism as defined by Stiell et al., to be very common.[23] In our sample, these injuries were not typically occult. Abnormal signs and symptoms including neurologic deficits, altered mental status, and Glasgow Coma Scale (GCS) < 15 were commonly noted on patient arrival, particularly for cases with supratentorial lesions found on CT scan (Type I and Type II pattern injuries). As expected, abnormal level of alertness and

	All patients N (%) N = 184	Pattern of posterior fossa injury			Clinical outcome	
		Type I N (%) N = 63	Type II N (%) N = 87	Type III N (%) N = 34	Clinically important injury N (%) N = 151	Neurosurgical intervention N (%) N = 110
Discharge home	49 (26.6)	12 (19.0)	18 (20.7)	19 (55.9)	30 (19.9)	7 (6.4)
Transfer to alternate in-patient facility	14 (7.6)	6 (9.5)	6 (6.9)	2 (5.9)	10 (9.1)	6 (5.5)
Discharge to rehabilitation	48 (26.1)	20 (31.7)	21 (24.1)	7 (20.6)	40 (26.5)	32 (29.1)
Death	52 (28.3)	19 (30.2)	30 (34.5)	2 (5.9)	52 (34.4)	52 (47.3)
Against Medical Advice (AMA)	1 (0.5)	1 (1.6)	0 (0.0)	0 (0.0)	1 (0.7)	0 (0.0)
Unknown[a]	20 (10.9)	5 (7.9)	12 (13.8)	3 (8.8)	18 (11.9)	13 (11.8)

[a]Unknown includes predominantly patients known to be discharged, but with lack of clarity in the clinical record if they were discharged home or to rehabilitation. To avoid misclassification bias they were left as unknown.

Table 5: **Discharge disposition by pattern of posterior fossa injury.**

abnormal behavior were frequently noted in patients with worse clinical outcomes and need for neurosurgical intervention. In prior literature, presenting Glasgow Coma Scale (GCS) < 8 is frequently associated with poor outcomes.[4,6,7,9,11–13,15] These abnormal neurologic signs were more frequently noted in the Type I and Type II injury patterns, and more prevalent in patients found to have clinically important injury.

Limitations

In describing our sample we chose to categorize the patterns of injury into three injury patterns. This system is not arbitrary and was informed by prior research. However, outcomes are related not to just location of injuries, but to the types of injuries and severity (e.g. size of hemorrhage). A large epidural hematoma is not the same as a small amount of subarachnoid hemorrhage. There is no universal grading or score for severity of injury. Our categorization of injuries was based on the initial CT imaging, limiting the ability to account for developing or unrecognized injuries. Some traumatic injuries may have been initially missed or identified injuries may have worsened on repeat imaging. We deliberately chose to focus on injury patterns observed on initial CT imaging as this is concordant with the information that emergency physicians and neurosurgeons will have available in the initial evaluation and management of patients.

The NEXUS validation sample excluded patients who did not undergo tomographic head imaging and could be vulnerable to verification or work-up bias. However, in studies conducted by Mower et al. on samples of 1266 and 368 consecutive patients evaluated for blunt head injuries without brain imaging during the same time period of the derivation and validation data set collection, none had brain injury or required neurosurgical intervention at a three-month follow-up. Thus, the potential for verification bias of injuries and missed injuries was 0.00% (95% CI, 0.00%–1.00%).[11,18] Our research was conducted at four trauma centers in the state of California and the results may be less applicable or generalizable to medical environments which differ. Size, locality of the medical center, and patient population, among other factors, may affect the cases presenting and the outcomes. Our data is limited to the patients who survive to the hospital and initial CT imaging, which is of most relevance to the practicing clinician. The epidemiology and mortality among all head injured patients requires further study including autopsy data on those who die in the field. Our sample size reduces the ability to perform stratified or predictive analysis of the sample. The data collected for the validation set was restricted to a select number of variables. There is very little missing data due to the patients being in extremis; only 2 of 49 patients bypassed any data collection due to instability, with the remaining 47 unstable patients having a physicians' assessment prior to CT scan. Nonetheless there are unknown data, almost always involving patients who presented obtunded or due to their altered mental status could not provide historical information such as medications, and whether they experienced loss of consciousness. At times some of these unknown variables such as coagulopathy, or the patient's underlying comorbidities might impact their clinical outcomes. Some disposition data was unknown when subjects were transferred to other facilities, and in some cases it was difficult to determine whether a patient was discharged home or to a rehabilitation facility (categorized as unknown).

Conclusion

In conclusion, posterior fossa injuries were uncommon in adults and rare in children. These injuries had significant morbidity and mortality when associated with supratentorial injuries. Isolated posterior fossa injuries had a more favorable prognosis. Not surprisingly, abnormal mental status and neurologic deficits were common in those with more serious injury and were associated with higher morbidity and mortality.

Our findings will enable clinicians to better recognize the spectrum of posterior fossa injuries and the importance of other intracranial injuries, thus enabling them to make more informed decisions regarding triage, resource utilization, and outcomes. Future research should focus on further stratification of these injuries to better define the optimal management of specific types of injuries, with consideration given to whether these injuries occur in isolation, or in conjunction with other intracranial injuries.

Contributors

RJC–literature search, analysis and interpretation of the data for the work, drafting the original manuscript, revision and editing; TG, SR, KB, RF, analysis of the data and revision of the manuscript; TEA, AQ, MG, GWH, RMR acquisition and interpretation of the data, and revision of the manuscript; WRW conception and design of the work, acquisition, analysis and interpretation of the data, critical revision of the manuscript. All authors give final approval of the version to be published; and agree to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

RJC and WRW have accessed and verified the underlying data reported in the manuscript, and were responsible for the decision to submit the manuscript.

Richelle J. Cooper, Gregory W. Hendey, Robert M. Rodriguez, and William R. Mower are all full professors.

Data sharing statement

The NEXUS Head CT data files and data dictionary are available upon request to the corresponding author, William R. Mower, MD, PhD, as of publication of the manuscript.

Declaration of interests

None of the authors have any conflicts of interest related to this research database or analysis.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at https://doi.org/10.1016/j.lana.2024.100760.

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