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Pediatric basilar skull fractures from multi-level falls: A systematic review and retrospective analysis

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ABSTRACT

Objective: Multi-level fall (MLF) accounts for 26.5%–37.7% of traumatic pediatric basilar skull fractures (BSFs). There is a dearth of information concerning recommendations for work-up, diagnosis, treatment, and otolaryngological follow-up of pediatric basilar skull fractures secondary to MLFs. Through a systematic literature review and retrospective review of an institution's trauma experience, we sought to identify clinical findings among pediatric MLF patients that indicate the need for otolaryngological follow-up.

Methods: A two-researcher team following the PRISMA guidelines performed a systematic literature review. PubMed, Web of Science, and EBSCO databases were searched August 16th' 2020 and again on November 20th' 2021 for English language articles published after 1980 using search terms Pediatric AND (fall OR "multi level fall" OR "fall from height") AND ("basilar fracture" OR "basilar skull fracture" OR "skull base fracture" OR "skull fracture"). Simultaneously, an institutional trauma database and retrospective chart review was performed for all patients under age 18 who presented with a MLF to a pediatric tertiary care center between 2007 and 2018.

Results: 168 publications were identified and 13 articles reporting pediatric basilar skull fracture data and MLF as a mechanism of injury were selected for review. MLF is the most common etiology of BSF, accounting for 26.5–37.7% of pediatric BSFs. In the retrospective review, there were 180 cases of BSF from MLF in the study period (4.2%). BSF and fall height were significantly associated ($p < 0.001$), as well as presence of a CSF leak and fall height ($p = 0.02$), intracranial hemorrhage (ICH) ($p = 0.047$), and BSF fracture type ($p < 0.001$). However, when stratified by age, these associations were only present in the younger group. Of those with non-temporal bone BSFs ($n = 71$), children with hemotympanum ($n = 7$) were approximately 18 times more likely (RR 18.3, 95% CI 1.89 to 177.02) than children without hemotympanum ($n = 64$) to have hearing loss at presentation (28.6% vs. 1.6% of patients).

Conclusions: MLF is the most common cause of pediatric basilar skull fractures. However, there is limited information on the appropriate work-up or otolaryngologic follow-up for this mechanism of injury. Our retrospective review suggests fall height is predictive for BSF, ICH, and CSF leak in younger children. Also, children with non-temporal bone BSFs and hemotympanum may represent a significant population requiring otolaryngology follow-up.

1. Introduction

Pediatric head trauma is associated with multiple etiologies, most commonly motor vehicle accidents, nonaccidental trauma, and falls [1]. An estimated 0.1%–2% of pediatric patients with head trauma have a skull base fracture (BSF) [2].

The skull base fractures can include multiple bones including the temporal, occipital, sphenoidal, and the sphenoethmoidal complex. The

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skull base portion of the occipital bone is defined as inferior to the nuchal ridge and occipital spur [3]. Skull base fractures are a common traumatic injury in the pediatric population and are associated with significant sequalae including cerebrospinal fluid (CSF) leaks, facial nerve injury, hearing loss and meningitis [4]. In the literature, multi-level falls (MLF) account for a significant amount of reported BSF [5]. MLF is defined as a stationary fall from any height and includes falls from vehicles, into bodies of water, or collision injuries.

Though multi-level falls (MLF) account for a significant percentage of traumatic pediatric basilar skull fractures (BSFs), there are limited guidelines on the indications for imaging or otolaryngological follow up [6]. This study's primary objective is to identify evidence-based recommendations for work-up, diagnosis, treatment, and otolaryngology follow-up of pediatric basilar skull fractures secondary to multi-level fall (MLF) through systematic review of published materials and a retrospective institutional analysis of a pediatric trauma database.

The retrospective portion of this study analyzes BSFs in a population <18 years of age from 2007 to 2018. This single institution serves a population of roughly 775,000–800,000 individuals aged <18 years and accounts for >85% of the hospital admission for basilar skull fractures in pediatric patients in the county [7,8].

2. Materials and methods

2.1. Systematic review

PubMed, Web of Science, and EBSCO databases were searched August 16th, 2020 and again on November 20th, 2021 for English language articles published after 1980 using search terms Pediatric AND ("fall" OR "multi level fall" OR "fall from height") AND ("basilar fracture" OR "basilar skull fracture" OR "skull base fracture" OR "skull fracture"). The citations of key articles were reviewed to identify any further relevant studies. This systematic review followed the instructions of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) criteria. This systematic review is exempt Institutional Review board (IRB) review.

A two-researcher team independently reviewed the article titles and abstracts to determine potential inclusion. Crosscheck of article references was performed to identify relevant studies, and for articles meeting criteria, full-text manuscripts were obtained and screened. Both authors independently screened, reviewed, and identified articles at every stage, and disagreements were settled through mutual discussion.

Inclusion criteria included the following:

- a pediatric study population (<18 years old) is reported
- the mechanism of injury is related to a fall

Exclusion criteria included the following:

- the study fails to report skull fracture specific data
- the article fails to report original data
- the article is not available in the English language

All available quantitative data related to BSF and unspecified skull fractures, included incidence and sequelae were collected and organized. Aggregate data was not amenable to statistical analysis. Lastly, the MINORS (Methodological Index for Non-Randomized Studies) score for non-comparative studies was used to evaluate each publication with pediatric BSF data, with an ideal score equating 16. The two-researcher team reviewed each publication independently and individual scores were averaged.

2.2. Retrospective review

A retrospective cohort of patients who presented with MLF-related injury to a pediatric tertiary care center between January 2007 and December 2018 were analyzed. Data were collected from the Rady Children's Hospital Trauma Database and Institutional Review Board approval was obtained. Patients included in the study had an ICD-9 code or an ICD-10 code for a fall-related injury (n = 4315).

Patients without an ICD code for a fall injury were excluded from the analysis. The presence of a BSF in fall-related injuries was assessed, and correlations between fall height and resulting sequelae were analyzed. Retrospective chart review of patients with a fall-related injury and confirmed BSF was used for secondary analysis. A BSF was classified as Computed Tomography (CT)-proven injury to the frontal, cribriform, ethmoid, sphenoid, temporal, or occipital bones (Fig. 1). Patients with full charts available for review were included in the analysis (n = 180). The variables analyzed were hemotympanum, intracranial hemorrhage, vertigo, hearing loss, and cerebral spinal fluid (CSF) leak.

Subgroups were defined as age less than 3.36 years or greater than 3.36 years, fall height and BSF type. Clinical characteristics were analyzed using χ^2 tests in SPSS v.27 (IBM, Armonk, NY, USA) and p values < 0.05 were taken to be significant.

3. Results

3.1. systematic review

A total of 168 publications were identified and 13 articles reporting pediatric basilar skull fracture data and MLF as a mechanism of injury were selected. A flow chart of the systematic review can be found in Fig. 2.

Kadish et al. first considered the rate of complications in pediatric patients with BSF identified on CT in 1995. Through a retrospective review of 239 patients, a subgroup of 114 patients with a "simple" BSF were found to be at low risk of complications and may not require hospital admission [9]. Similarly, in trauma patients with a normal neurological exam, Schunk et al. describe the rate of intercranial injury to be below 5% and neurosurgical follow up is necessary in less than 1% of cases [10].

Five articles discussed the mechanism of injury and presentation. Kim et al. note that though falls greater than 15 feet have a higher mortality rate, they are not predictive of Glasgow Coma Scale (GCS) score and do not cause significantly higher rate of intracranial injury [11]. Thoren et al. discuss the relationship between age and skull fracture pattern. They note that orbital roof fractures were the most common fracture site and children younger than 6 years old were more likely to have lateral frontobasal fractures [12]. Schaller et al. discuss the severity of anterior skull base fractures and associated injuries, while Magit et al. focus on the mechanism and financial implications [1,13]. Multilevel falls are the most common etiology in both studies. Similarly, Wang et al. found that high falls (>2 m) were the second most common etiology of skull fractures in children under the age of 18 years old behind motor vehicle collisions. In this set of patients, the rate of traumatic brain injury and other associated injuries was correlated with age [14].

Six articles report on the work up and management of patients with basal skull fractures. Perheentupa et al. found that falls were the second most cause of skull base fracture and the temporal bone was most commonly involved. Forty-three percent of these patients had an intracranial injury and the vast majority were discharged home [15]. In a longer follow-up study of 20 of these patients Perheentupa et al. showed that frontobasilar fractures, though associated with intracranial trauma, led to permanent sequalae in only a quarter of their patients [16]. The association between skull base fracture and CSF leak was analyzed by Leibu et al., in 2017. In the study population of 196 pediatric patients, fifty-four (28%) had a CSF leak which, in the majority of cases, resolved spontaneously. Fifteen patients developed delayed sequalae like hearing loss or facial paralysis [17]. Boruah et al. identified the association between nonaccidental trauma (NAT) and isolated skull fractures. More than half of the patients in their cohort with isolated skull fractures were suspected for NAT and falls were the most common

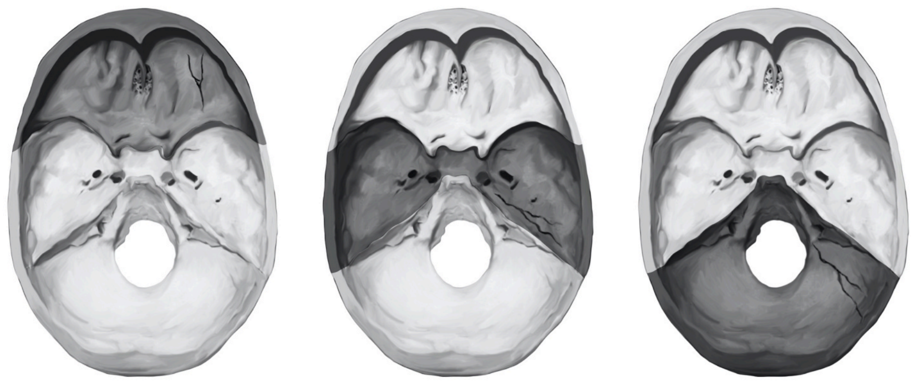

Fig. 1. Three distinct regions of the skull base shown with representative fractures in each. From left to right: anterior cranial fossa, middle cranial fossa, and posterior cranial fossa.

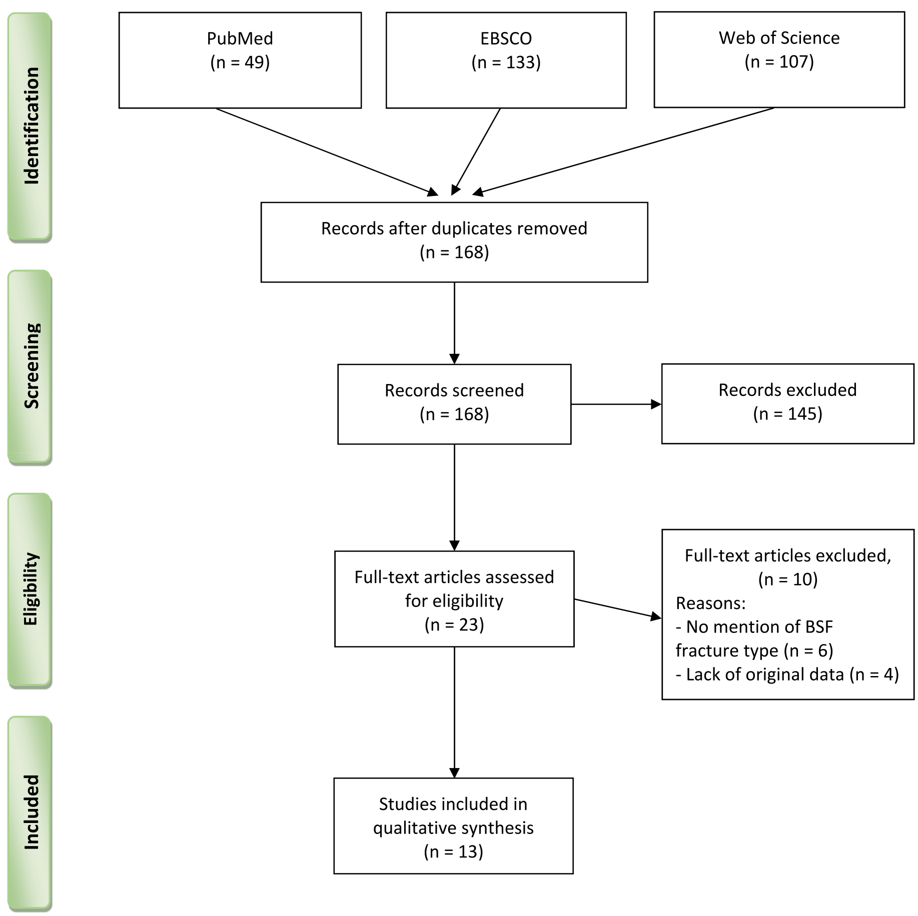

Fig. 2. PRISMA Systematic Review flow diagram.

stated mechanism of injury [18]. Tunik et al. address both the mechanism and outcomes of pediatric head trauma in the emergency department. They address the importance of CT imaging and found that physical exam findings classically associated with skull base fractures (periorbital and retroauricular ecchymoses) are neither sensitive nor specific to skull base fractures identified on CT [4]. Lastly, Michiwaki et al. analyzed the use of CT in patients with minor head trauma, defined as events that did not involve a loss of consciousness or require immediate surgery. In their study, CT examinations were more often performed after falls and in younger populations, and only detected abnormalities in 1.9% of patients [19].

3.2. *Retrospective review*

In the twelve-year study period, there were 4315 multi-level fall cases in the database. Fall height was known in 4137 of the cases and BSF status in 4247 cases. The incidence of BSF after MLF for the study period was 4.2% or 6.39 cases per 1000 person-years (n = 180). Of those with a BSF, 109 (60.5%) were male while 71 (39.4%) were female (Table 1). The patients ranged from 0.23 years to 14.9 years and the median age was 3.62 years.

Falls from heights below 6 feet were the most common, accounting for 57.8% of the total falls (n = 104). Falls from over fifteen feet accounted for 26.1% (n = 47) of the total while falls from a moderate

Table 1
Demographic characteristics of patients with basilar skull fractures (n = 180).

Characteristic	Number (%)
Sex	
Male	109 (60.5)
Female	71 (39.4)
Age	
<3.36 years	83 (46.1)
>3.36 years	97 (53.9)
Fall Height	
<6 feet	104 (57.8)
>6 and < 15 feet	29 (16.1)
>15 feet	47 (26.1)
Skull Fracture Type	
Temporal bone	109 (60.6)
Non-temporal bone	71 (39.4)
GCS on Admission	
14-15	150 (83.3)
<14	30 (16.7)
Clinical Findings	
Hemotympanum	72 (40)
CSF leak	7 (3.9)
Facial nerve injury	19 (10.6)
Hearing loss	22 (12.2)
Vertigo	3 (1.7)
Battle sign	6 (3.3)
Raccoon sign	42 (23.3)
Radiological Findings	
Intracranial bleed	65 (36.1)

Abbreviations: GCS, Glasgow Coma Scale; CSF, cerebrospinal fluid.

height made up 16.1% (n = 29). As shown in Table 3, BSF presence and fall height were significantly associated ($p < 0.001$), as well as presence of a CSF leak and fall height ($p = 0.02$), intracranial hemorrhage presence ($p = 0.047$), and BSF type ($p < 0.001$). However, when stratified by age, these associations were only present in the younger age group.

Fractures of the temporal bone were the most common type of skull fracture identified and made up 60.6% of the total (n = 109). Of those with non-temporal bone BSFs (n = 71), children with hemotympanum (n = 7) were approximately 18 times more likely (RR 18.3, 95% CI 1.89 to 177.02) than children without hemotympanum (n = 64) to have hearing loss at presentation (28.6% vs. 1.6% of patients). There was no significant association between CSF leak and loss of consciousness, GCS, ICH type, facial nerve injury, hearing loss, vertigo, hemotympanum, Battle sign, or racoon sign ($p > 0.05$).

4. Discussion

The purpose of the systematic review and retrospective analysis was to determine evidence-based guidelines for otolaryngological follow up in patients with a skull base fracture secondary to a multi-level fall. Although work has been done concerning the rates of complications, indications for CT scans, and epidemiology of these injuries, current approaches to care and follow-up are variable. This review identified MLF as the most common etiology of BSF in nine of eleven qualifying studies, accounting for 26.7–37.7% of pediatric BSFs (Table 2). MINORS scores for the articles included in this review ranged from 6 to 11 which shows the variable study quality.

Patients presenting with a BSF secondary to a MLF were more often male and these injuries were more common in younger populations compared to other mechanisms of injury [12,19]. This observed sexual difference may be explained by the male-skewed distribution of children presenting with falls, though specific fall mechanism and fall height also likely play a role [20]. Perheentupa et al. and Leibu et al. reported the temporal bone as the most common fracture location in 63.5% and 57% of patients respectively [15,17]. This aligns with past work in pediatric populations and differs from current literature in adults, most likely due to anatomic differences in these populations [17,21]. Regarding the types of fractures in these patients, this review found linear, non-displaced fractures as the most common [4,19].

Table 2
Studies included in the systematic review of basilar skull fractures due to multi-level falls.

Publication	Total Patients	Patient Selection	MLF %	#1 Etiology	Minors Score
Michiwaki 2021	2405	Minor Head Trauma	37.5	MLF	7
Boruah 2021	45	Skull Fracture	75.6	MLF	8
Magit 2020	729	BSF	35.8	MLF	8
Wang 2018	393	Traumatic Skull Fracture	43.7	MLF	8
Leibu 2017	196	BSF and TBI	72.9	MLF	8
Tunik 2016	558	BSF after Head Trauma	26.5	MLF	11
Perheentupa 2012	20	Frontobasal BSF	10.0	MVA	7
Schaller 2012	49	Frontobasal BSF	42.9	MLF	8
Thorén 2011	43	Frontobasal BSF	40.0	MLF	8
Perheentupa 2010	63	BSF	31.7	MVA	6
Kim 2000	729	Head Trauma from Fall	90.8	MLF	8
Schunk 1996	313	Trauma with Normal Neuro Exam	20.7	MLF	8
Kadish 1995	239	BSF	37.7	MLF	6

Abbreviations: BSF, basal skull fracture; TBI, traumatic brain injury.

Table 3
Pearson Chi-squared statistics among patients with basilar skull fractures and the association between age, CSF leak, and injury characteristics. Chi-squared statistics showing the relationship between fall height and basilar skull fractures among all patients presenting after a fall is also shown.

BSF Patients	All BSF Patients (N = 180)		Age Group 1 (N = 83)		Age Group 2 (N = 97)	
	$\chi2$ value	p value	$\chi2$ value	p value	$\chi2$ value	p value
CSF Leak	–	–	–	–	–	–
Fall Height	8.128	0.017*	11.652	0.003*	0.370	0.831
BSF Fracture Type	59.680	<0.001*	47.271	<0.001*	2.384	1
ICH	3.938	0.047*	7.424	0.006*	0.010	0.92
ICH Type	43.178	<0.001*	31.647	<0.001*	16.013	0.141
All MLF Patients	**All Patients (N = 4137)**		**Total Age Group 1 (N = 2078)**		**Total Age Group 2 (N = 2059)**	
	$\chi2$ value	p value	$\chi2$ value	p value	$\chi2$ value	p value
BSF vs Fall Height	21.139	<0.001*	19.779	<0.001*	5.916	0.052

P values < 0.05 are taken as significant and marked with an *. Abbreviations: BSF – basilar skull fracture.
MLF – multi-level fall, CSF – cerebrospinal fluid, ICH – intracranial hemorrhage.

Tunik et al. and Kadish et al. both identify the importance of using both imaging and pertinent physical exam findings in the identification of BSFs [4,9]. Nearly a third of patients with MLF-related BSF were only evident on CT while another third were only demonstrated on physical exam. Additionally, physical exam findings classically associated with BSF like periorbital ecchymoses (Raccoon sign) and retroauricular ecchymoses (Battle sign), were neither sensitive nor specific to BSF or significantly correlated with intracerebral injury [4]. Hemotympanum is the most common physical exam finding of basilar skull fracture in this review which is consistent with previously published reports [9,22].

While modern CT techniques have improved the sensitivity of scans in the identification of skull base fractures, Tunik et al. posit that standard trauma CT scans may miss a significant portion of children with

BSFs [4]. In this review, patients with isolated BSFs due to MLFs and benign neurological exams are at low risk for adverse outcomes and may be candidates for discharge with close outpatient follow-up [4,17]. This aligns with previously published work in this area [23,24]. In the studies that report MLF-specific data, rates of associated intracranial injuries like hemorrhage and CSF leak were varied. Kim et al. report that in patients with trauma from a MLF, subarachnoid hemorrhage is the most common type of intracranial bleeding, occurring in 2.4% of cases, and the overall rate of any type of intracranial bleeding was 11.2% [11]. In patients with confirmed skull fracture from falls, Wang et al. understandably found these rates to be increased to between 40 and 47% with epidural hemorrhages occurring in more than half these patients [14].

Regarding recovery after head trauma, Perheentupa et al. note that 16% of patients had permanent neurological problems over the course of their 6–12 month follow-up period [15]. Similarly Leibu et al. report hearing loss and cranial nerve deficits as the most common long term deficits, with a significant portion of these being delayed onset [17]. The articles included in this review were limited in the variety of their study designs. Twelve of thirteen studies are retrospective analyses and only two have any form of longitudinal follow-up. Consequently, the current state of the literature may be missing a significant portion of the associated morbidity from these injuries.

No studies provided evidence-based recommendations on the diagnosis, treatment, or need for otolaryngological follow-up of pediatric basilar skull fractures secondary to MLF. Although MLF are the most common cause of pediatric basilar skull fractures, there is a dearth of information on the appropriate work-up or otolaryngologic follow-up for this mechanism of injury.

4.1. Retrospective review

In our cohort of pediatric patients presenting after multilevel falls, basilar skull fractures were uncommon and significantly associated with falls from greater than 15 feet. The incidence of BSF from falls in our study was 4.2% which is similar to past work with this mechanism of injury [1,4]. Our study also suggests that fall height is predictive for BSF incidence and CSF leaks in younger children. This may be due to age-related differences in skeletal development or changes in the cranium to facial skeleton size ratio, both of which have been posited in the literature [25–27]. Because the significant association between fall height and BSF incidence was present only in younger children, other factors such as specific mechanism of fall may be involved. Further investigation is required to conclusively identify clinical findings that indicate the need for ENT follow-up.

Similar to previous work, temporal bone fractures were the most common BSF in this cohort [15,17]. A key finding in this analysis was the significantly increased risk for hearing loss in patients with the combination of non-temporal bone BSFs and hemotympanum. While subjective hearing loss has been linked to both hemotympanum and fractures of the temporal bone in the literature, this work suggests fractures elsewhere in the skull base may put patients at higher risk for the development of this symptom [22,28,29]. Patients with this pattern of injury may represent a significant population requiring otolaryngological follow-up.

This study also found that classic physical exam findings associated with BSF like periorbital and retroauricular ecchymoses are unreliable markers for BSF identified on CT. Only 26% of patients with a BSF in our cohort exhibited these clinical findings. Similarly, Tunik et al. notes nearly a third of pediatric patients with BSF identified on CT scan may not have associated physical exam findings [4]. Clinical assessment in children presenting after falls may also be misleading [11]. In our cohort, 83% of children with a BSF in cohort presented with a GCS of 14 or greater. Due to the risk of sequelae, work up and imaging for suspected BSFs should be guided in part by common mechanisms of injury, like multi-level falls.

This study is limited by its reliance on identified skull base fractures. These injuries were not always suspected and consequently every patient presenting after a fall did not undergo imaging studies. Given the significant rate of asymptomatic skull base fracture in the literature, some fractures in this cohort may have gone unidentified. Secondly, this work is limited by its qualification of hearing loss. In this study, hearing loss was characterized on a subjective exam rather than pre-event and post-event audiology. Though this method effectively identifies significant deficits, it is unlikely to catch subtler changes in hearing, and therefore may lead to an underrepresentation of the hearing loss in this cohort. Lastly, like the articles included in our systematic review, this retrospective analysis is limited by its follow up. Given this size and expansive nature of this cohort, limited monitoring was obtained beyond the acute phase of care. Though this may limit the generalizability of this work, we believe it provides an accurate picture of skull base fractures from falls at a large pediatric trauma center.

5. Conclusion

Multilevel falls are a common culprit for skull base fractures in pediatric populations. This systematic review outlines the lack of quality prospective studies with significant follow up in the current literature and the limited indications for otolaryngological involvement. While temporal bone fractures were the most common location for skull base fractures, our retrospective analysis showed that patients with non-temporal bone fractures and hemotympanum may be a population requiring otolaryngological follow up. Risk stratification by mechanism of injury, especially in patients under the age of three years, can help identify skull base fractures in this population. Further research with a larger prospective cohort of patients is necessary to support this conclusion and guide management.

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Author roles

Patrick Barba – Manuscript writing, Table and Figure design.
Joshua Stramiello – Study conception, Data collection and analysis, Critical manuscript editing.
Zachary Nardone – Data collection and analysis.
Seth Walsh-Blackmore – Data collection and analysis.
Javan Nation – Study conception, Data collection.
Romeo Ignacio – Study conception, Critical manuscript editing.
Anthony Magit – Study conception, Data collection and analysis, Critical manuscript editing.

Declaration of competing interest

None.

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