Risks, costs, and outcomes of cerebrospinal fluid leaks after pediatric skull fractures: a MarketScan analysis between 2007 and 2015

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OBJECTIVE Skull fractures are common after blunt pediatric head trauma. CSF leaks are a rare but serious complication of skull fractures; however, little evidence exists on the risk of developing a CSF leak following skull fracture in the pediatric population. In this epidemiological study, the authors investigated the risk factors of CSF leaks and their impact on pediatric skull fracture outcomes.

METHODS The authors queried the MarketScan database (2007–2015), identifying pediatric patients (age < 18 years) with a diagnosis of skull fracture and CSF leak. Skull fractures were disaggregated by location (base, vault, facial) and severity (open, closed, multiple, concomitant cerebral or vascular injury). Descriptive statistics and hypothesis testing were used to compare baseline characteristics, complications, quality metrics, and costs.

RESULTS The authors identified 13,861 pediatric patients admitted with a skull fracture, of whom 1.46% (n = 202) developed a CSF leak. Among patients with a skull fracture and a CSF leak, 118 (58.4%) presented with otorrhea and 84 (41.6%) presented with rhinorrhea. Patients who developed CSF leaks were older (10.4 years vs 8.7 years, $p < 0.0001$) and more commonly had skull base (n = 183) and multiple (n = 22) skull fractures ($p < 0.05$). These patients also more frequently underwent a neurosurgical intervention (24.8% vs 9.6%, $p < 0.0001$). Compared with the non-CSF leak population, patients with a CSF leak had longer average hospitalizations (9.6 days vs 3.7 days, $p < 0.0001$) and higher rates of neurological deficits (5.0% vs 0.7%, $p < 0.0001$; OR 7.0; 95% CI 3.6–13.6), meningitis (5.5% vs 0.3%, $p < 0.0001$; OR 22.4; 95% CI 11.2–44.9), nonroutine discharge (6.9% vs 2.5%, $p < 0.0001$; OR 2.9; 95% CI 1.7–5.0), and readmission (24.7% vs 8.5%, $p < 0.0001$; OR 3.4; 95% CI 2.5–4.7). Total costs at 90 days for patients with a CSF leak averaged \$81,206, compared with \$32,831 for patients without a CSF leak ($p < 0.0001$).

CONCLUSIONS The authors found that CSF leaks occurred in 1.46% of pediatric patients with skull fractures and that skull fractures were associated with significantly increased rates of neurosurgical intervention and risks of meningitis, hospital readmission, and neurological deficits at 90 days. Pediatric patients with skull fractures also experienced longer average hospitalizations and greater healthcare costs at presentation and at 90 days.

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KEYWORDS CSF leak; pediatric; traumatic brain injury; skull fracture

SKULL fractures are commonly associated with pediatric traumatic brain injury^{1,2,9} due to blunt trauma.^{7,13} The mechanism of trauma, extent of fracture comminution, and presence of associated intracranial injuries determine the appropriate clinical approach, risk of neurological deterioration, and overall prognosis.^{1,7} Most isolated nondepressed linear skull fractures can be managed conservatively,^{3,4,6,8,9,12,17,21–23,26} and past studies have

avored discharge over 23-hour observation for these patients.^{4,6,21} However, nonlinear skull fractures, including open, depressed, and basilar fractures, are more strongly associated with intracranial pathology and morbidity^{1,7,10,19,20,27} and thus require careful clinical attention. CSF leaks are a known complication of these fractures^{5,10,11,16,28} and arise due to fistulous connection between the intradural and extracranial space.¹³ CSF leaks often present as

ABBREVIATIONS EVD = external ventricular drain; ICD-9-CM = *International Classification of Diseases, 9th Revision, Clinical Modification*; LOS = length of stay.

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clear rhinorrhea or otorrhea within the first 48 hours of injury,^{25,27–29} and they are estimated to occur in 2.3% of all pediatric skull fractures¹ and 10%–30% of skull base fractures.^{5,11,13,27,28}

While most CSF leaks resolve spontaneously,^{11,27,28} they substantially increase the risk of meningitis and encephalitis,^{11,13,16,20,27} though risk estimates vary widely among retrospective studies^{11,13,27} and are not as well studied in the pediatric population. Moreover, in the absence of consensus treatment guidelines, there is substantial interinstitution difference in management, in particular regarding the need for neurosurgical intervention.^{7,11,13,15} The literature indicates that leaks requiring surgical intervention, or persisting over time, are associated with higher rates of meningitis and mortality.^{13,16}

Although CSF leaks are known to occur after skull fractures in a minority of cases, precise risk estimates in the pediatric population are extremely limited,^{1,16} and our current understanding derives from single-institution studies of skull base injuries.^{13,20,24,27,28} In this study, we used the MarketScan database between 2007 and 2015 to assemble a large cohort of pediatric patients with skull fractures. We examined the characteristics and clinical outcomes of pediatric skull fracture patients with and without CSF leaks, and we longitudinally assessed the healthcare costs associated with the care of these patients.

Methods

Data Source

This study obtained a sample of the MarketScan Commercial Claims and Encounters Database (Truven Health Analytics) from January 1, 2007, to December 31, 2015, inclusive. This database is a collection of commercial inpatient, outpatient, and pharmaceutical claims of more than 75 million employees, retirees, and dependents representing a substantial portion of the US population covered by employer-sponsored insurance. MarketScan contains 53 million inpatient records, 40 million with employer-sponsored insurance, 3.7 million with Medicare Part B, and 6.8 million with Medicaid. The data are updated quarterly, with all new records becoming available within 15 months of service and 91% of claims available within 5 months. Due to MarketScan's sourcing from large employers, it boasts of superior longitudinal tracking of patients' data. MarketScan data sets are publicly available to researchers for a fee per year of data. The MarketScan database contains *International Classification of Diseases, 9th Revision, Clinical Modification* (ICD-9-CM) and *10th Revision, Clinical Modification* codes, Current Procedural Terminology codes, Diagnosis Related Group codes, and National Drug Codes.

Sample

The sample in this study consisted of 13,861 patients with a skull fracture (ICD-9-CM codes 800.xx–804.xx). Records were then queried to identify which patients developed a CSF leak by ICD-9-CM code 388.61 or 349.81. Patients 18 years of age or older were excluded. Patients were categorized as having a skull fracture with or without CSF leak.

Outcomes and Variables

Outcomes included the development of meningitis or neurological deficits, readmission rates, inpatient mortality, nonroutine discharge (defined as any discharge not to the patient's home), and costs within 90 days from index admission. Length of stay (LOS) was also determined. Surgical treatment modalities were also compared between groups. Patient-level variables, including age at diagnosis, sex, year of admission, and quality and cost metrics, were taken directly from the claims data. Complications were assessed using ICD-9-CM codes.

Statistical Analysis

The chi-square test, t-test, rank-sum test, and logistic regression were utilized to assess significant differences in demographic data, skull fracture type, surgical treatment modalities, 90-day complications, quality outcomes, and payments among the groups. The p values were interpreted as significant if less than 0.05.

Patient Involvement

As this study includes only analysis of secondary de-identified data, it was not considered human subject research and received exemption from IRB approval at our institution.

Results

In the MarketScan database we identified 13,861 pediatric patients (< 18 years of age) with skull fractures treated between 2007 and 2015, of whom 202 (1.46%) also had a CSF leak. Table 1 compares this group of 202 patients who had a skull fracture and a CSF leak with the rest of the group (13,659 patients), who had a skull fracture and no CSF leak. The mean age of patients with a CSF leak was 10.4 years (range 0–17 years) compared with a mean age of 8.7 years (range 0–17 years) in the overall cohort of patients with skull fractures ($p < 0.0001$). Among the skull fracture patients with a CSF leak, 118 (58.4%) presented with otorrhea and 84 (41.6%) presented with rhinorrhea. Vascular injuries, including hemorrhage and arterial dissection, were observed in 123 patients (60.9%) with CSF leaks and in 5565 of the 13,659 patients (40.7%) in the general cohort ($p < 0.0001$). Neurosurgical intervention was performed in 50 patients (24.8%) with a CSF leak and in 1313 (9.6%) of the 13,659 patients without a CSF leak ($p < 0.0001$).

First, the longitudinal impact of skull fractures on healthcare expenditure and LOS was assessed (Figs. 1 and 2). The total number of skull fracture admissions declined by more than 40% between 2007 and 2015 (Fig. 1), from roughly 70 in every 100,000 admissions to 45. Over the same interval, the average LOS fell from 4.2 days to 3.4 days (–19%), and the mean total cost increased from \$35,661 to \$38,402 (+7.1%) (Fig. 2).

Skull fractures with and without CSF leaks were stratified by fracture location (Table 1), with skull base fractures occurring more frequently in the CSF leak population ($n = 183$; 90.6%) than in the non-CSF leak population ($n = 7162$; 52.4%) ($p < 0.0001$). Closed fractures, including depressed and growing fractures, represented the majority

TABLE 1. Demographics and clinical characteristics

Variable	Skull Fractures		p Value
	w/o CSF Leak (n = 13,659)	w/ CSF Leak (n = 202)	
Age in yrs, mean $\pm$ SD	8.7 $\pm$ 6.2	10.4 $\pm$ 5.5	<0.0001
Female	4686 (34.3)	61 (30.1)	0.1331
Type of CSF leak			
Otorrhea	NA	118 (58.4)	NA
Rhinorrhea	NA	84 (41.6)	NA
Vascular injury	5565 (40.7)	123 (60.9)	<0.0001
Non-CSF otorrhea or rhinorrhea	242 (1.8)	22 (10.9)	<0.0001
Neurosurgical procedure	1313 (9.6)	50 (24.8)	<0.0001
Skull fracture type			
Base	7162 (52.4)	183 (90.6)	<0.0001
Open	401 (2.9)	16 (7.9)	<0.0001
No cerebral injury	192 (1.4)	8 (4)	0.0033
Hemorrhage	164 (1.2)	6 (3)	0.0277
Laceration	84 (0.6)	5 (2.5)	0.0013
Closed	6968 (51)	176 (87.1)	<0.0001
No cerebral injury	5280 (38.7)	143 (70.8)	<0.0001
Hemorrhage	3020 (22.1)	87 (43.0)	<0.0001
Laceration	635 (4.6)	21 (10.4)	0.0002
Vault	5696 (41.7)	76 (37.6)	0.1452
Open	499 (3.7)	13 (6.4)	0.0471
No cerebral injury	266 (1.9)	5 (2.5)	0.6306
Hemorrhage	210 (1.5)	5 (2.5)	0.3112
Laceration	109 (0.8)	7 (3.5)	<0.0001
Closed	5469 (40)	67 (33.1)	0.0246
No cerebral injury	3834 (28.1)	37 (18.3)	0.0011
Hemorrhage	2496 (18.3)	30 (14.9)	0.1603
Laceration	459 (3.4)	9 (4.5)	0.4365
Facial fracture	4906 (35.9)	78 (38.6)	0.6353
Multiple fractures	854 (6.3)	22 (10.9)	0.0109

NA = not applicable.

Values are presented as the number (%) of patients unless otherwise indicated. Boldface type indicates statistical significance.

of skull base fractures in both groups (96.2% and 97.3%, respectively). They accounted for 87.1% (n = 176) of the fractures in the CSF leak population and 51% (n = 6968) in the non-CSF leak group (p < 0.0001). Closed skull base fractures with cerebral hemorrhage and laceration occurred in 43.0% (n = 87) and 10.4% (n = 21), respectively, of CSF leak patients, compared with 22.1% (n = 3020) and 4.7% (n = 635) of the non-CSF leak cohort (p < 0.0001 for hemorrhage; p = 0.0002 for laceration). A lack of cerebral injury was more frequently seen than cerebral hemorrhage or laceration across both populations with closed skull base fractures, though it represented a larger share in the population with CSF leaks (n = 143 [70.8%] vs 5280 [38.7%], p < 0.0001). Open vault skull fractures represented 6.4% (n = 13) of the fractures in the CSF leak popula-

tion and 3.7% (n = 499) in the non-CSF leak population (p = 0.0471). Closed vault fractures were seen in 33.1% (n = 67) of the CSF leak patients and in 40.1% (n = 5469) of the non-CSF leak patients (p = 0.0246). Multiple fractures were present in 10.9% (n = 22) of the CSF leak population and 6.3% (n = 854) of the non-CSF leak population (p = 0.0109).

The modes and rates of neurosurgical intervention were quantified in the CSF leak and non-CSF leak fracture cohorts (Table 2). Of the 202 patients with a CSF leak, 6 (3.0%) underwent decompressive craniectomies compared with 67 (0.5%) in the general cohort (p < 0.0001; OR 6.0; 95% CI 2.6–14.1). Sixteen patients (7.9%) with a CSF leak received craniotomies compared with 616 patients (4.5%) in the non-CSF leak population (p = 0.0278). Differences in external ventricular drain (EVD) (n = 8 [4.0%] vs 129 [0.9%], p < 0.0001) and lumbar drain (n = 27 [13.3%] vs 19 [0.1%], p < 0.0001) placement were also noted between patients with CSF leak and those without. Rates of skull fracture fragment elevation were not statistically different between groups. Overall, patients with a CSF leak were more likely to receive craniotomies (OR 1.7; 95% CI 1.0–3.0), EVDs (OR 4.2; 95% CI 2.0–8.7), and lumbar drains (OR 107.5; 95% CI 58.7–196.8) than patients without CSF leaks.

Patients with CSF leaks experienced worse 90-day outcomes than patients without CSF leaks (Table 3). However, there was no significant difference in mortality between groups (n = 2 [1.0%] vs 200 [1.5%], p = 0.5507). Compared with the non-CSF leak population, patients with a CSF leak had a longer average LOS (9.6 days vs 3.7 days, p < 0.0001) and higher rates of neurological deficits (5.0% vs 0.7%, p < 0.0001), meningitis (5.5% vs 0.3%, p < 0.0001), nonroutine discharges (6.9% vs 2.5%, p < 0.0001), and readmission (24.7% vs 8.5%, p < 0.0001). Patients with a CSF leak were found to be at a higher risk for neurological deficits (OR 7.0; 95% CI 3.6–13.6), meningitis (OR 22.4; 95% CI 11.2–44.9), nonroutine discharge (OR 2.9; 95% CI 1.7–5.0), and readmission at 90 days (OR 3.4; 95% CI 2.5–4.7).

Costs incurred at the index hospitalization and at 90 days were quantified (Table 3). Costs and payments were significantly increased for patients with a CSF leak. At the initial hospitalization, average physician payments were greater for the care of patients with a CSF leak (\$2639) than for non-CSF leak patients (\$1599) (p < 0.0001). Hospital payments (\$59,128 vs \$24,092, p < 0.0001) and total payments (\$65,833 vs \$28,426, p < 0.0001) were similarly increased. Total costs at 90 days for CSF leak patients averaged \$81,206 compared with \$32,831 for patients without CSF leaks (p < 0.0001).

Readmission events in CSF leak patients were studied in detail (Table 4). Of the 50 patients with CSF leak who were readmitted, 18 (36.0%) suffered complications from a skull base fracture and 10 (20.0%) were rehabilitating from a surgical procedure. Other causes of readmission were complications from CSF rhinorrhea (n = 8; 16.0%), acquired head deformities (n = 5; 10.0%), skull vault fractures (n = 5; 10.0%), and CSF otorrhea (n = 4; 8.0%).

The rates of neurosurgical intervention in patients with CSF leaks were further stratified by fracture location (Ta-

FIG. 1. Skull fracture admissions per 100,000.

FIG. 2. Impact on the healthcare system over time.

TABLE 2. Surgical procedures

Variable	No. of Patients (%)		OR (95% CI)	p Value
	Skull Fracture w/o CSF Leak (n = 13,659)	Skull Fracture w/ CSF Leak (n = 202)		
Craniectomy	67 (0.5)	6 (3.0)	6.0 (2.6–14.1)	<0.0001
Craniotomy	616 (4.5)	16 (7.9)	1.7 (1.0–3.0)	0.0278
Skull fracture fragments elevated	659 (4.8)	14 (6.9)	1.5 (0.8–2.5)	0.1991
Lumbar drain placed	19 (0.1)	27 (13.4)	107.5 (58.7–196.8)	<0.0001
EVD placed	129 (0.9)	8 (4.0)	4.2 (2.0–8.7)	<0.0001

Boldface type indicates statistical significance.

TABLE 3. Outcomes

Variable	Skull Fracture w/o CSF Leak (n = 13,659)	Skull Fracture w/ CSF Leak (n = 202)	OR (95% CI)	p Value
90-day outcomes, no. (%)				
LOS	3.7 ± 7.5	9.6 ± 15.3	NA	<0.0001
Neurological deficits	98 (0.7)	10 (5.0)	7.0 (3.6–13.6)	<0.0001
Meningitis	34 (0.2)	11 (5.4)	22.4 (11.2–44.9)	<0.0001
Nonroutine discharge	335 (2.5)	14 (6.9)	2.9 (1.7–5.0)	<0.0001
Readmissions	1158 (8.5)	50 (24.8)	3.4 (2.5–4.7)	<0.0001
Mortality	200 (1.5)	2 (1.0)	0.65 (0.2–2.7)	0.5507
Cost outcomes				
Index hospitalization				
Physician payments	\$1,599	\$2,639	NA	<0.0001
Hospital payments	\$24,092	\$59,128	NA	<0.0001
Total payments	\$28,426	\$65,833	NA	<0.0001
90-day costs				
TBI-related costs	\$15,870	\$30,891	NA	<0.0001
Total costs	\$32,831	\$81,206	NA	<0.0001

TBI = traumatic brain injury.

Boldface type indicates statistical significance.

ble 5). Of the 176 patients with closed skull base fractures and CSF leaks, 42 underwent a neurosurgical operation (OR 0.4; 95% CI 0.2–1.0; $p < 0.0357$). Of the 13 patients with open vault fractures, 9 underwent a neurosurgical operation (OR 7.2; 95% CI 2.1–24.6; $p < 0.0003$).

A logistic regression analysis was used to analyze covariates that could be predictive of meningitis risk (Table 6). Of the 6 covariates used in the regression, only neurosurgical intervention (OR 5.5; 95% CI 2.9–10.3; $p < 0.0001$) and the presence of CSF rhinorrhea (OR 26.5; 95% CI 10.4–59.8; $p < 0.0001$) or CSF otorrhea (OR 7.1; 95% CI 2.2–19.0; $p < 0.004$) were statistically significant. Other factors, including vault or base fractures, non-CSF otorrhea or rhinorrhea, and sex, were not significant.

Discussion

Skull fractures occur in 10%–30% of pediatric head trauma injuries^{14,18} and represent a leading cause of mor-

bidity. In this study, we used the MarketScan database to assemble, to the best of our knowledge, the largest cohort of pediatric skull fracture patients with CSF leaks in the literature. We found that 1.46% of pediatric skull fracture patients had a CSF leak, which is lower than previously reported in the pediatric (2.3%) and adult (10%–30%) populations. Our reported incidence of CSF leak (2.49%) among skull base fractures was similar to the rate (2.33%) reported by McCutcheon et al.,¹⁶ though substantially lower than that observed by Leib et al.¹³ (28%). While rates of neurological deficits, meningitis, and nonroutine discharge were low in both the CSF leak and non-CSF leak groups, we demonstrated that a CSF leak significantly increased the risk for these adverse outcomes. Patients with CSF leaks were 7 times more likely to have a neurological deficit and 22 times more likely to develop

TABLE 5. Neurosurgical intervention in CSF leak patients stratified by skull fracture type

Variable	No. of Patients (%)		OR (95% CI)	p Value
	No Surgery (n = 152)	Surgery (n = 50)		
Base	137 (90.1)	46 (92.0)	0.6 (0.2–1.4)	0.1973
Open	11 (7.2)	5 (10.0)	1.3 (0.4–3.9)	0.6591
Closed	134 (88.2)	42 (84.0)	0.4 (0.2–1.0)	0.0357
Vault	48 (31.6)	28 (56.0)	2.2 (1.2–4.2)	0.0108
Open	4 (2.6)	9 (18.0)	7.2 (2.1–24.6)	0.0003
Closed	46 (30.3)	21 (42.0)	1.4 (0.7–2.7)	0.2821

Boldface type indicates statistical significance.

TABLE 4. Reasons for readmission following the development of CSF leaks

Variable	No. of Patients (n = 50)	% of Patients
Skull base fracture	18	36.0%
Rehabilitation from surgical procedure	10	20.0%
CSF rhinorrhea	8	16.0%
Acquired deformity of the head	5	10.0%
Skull vault fracture	5	10.0%
CSF otorrhea	4	8.0%

TABLE 6. Logistic regression analysis to identify predictors of meningitis

Variable	OR	95% CI	p Value
Neurosurgical intervention	5.5	2.9–10.3	<0.0001
CSF leak	14.1	6.6–29.0	<0.0001
Rhinorrhea	26.5	10.4–59.8	<0.0001
Otorrhea	7.1	2.2–19.0	0.004
Non-CSF leak otorrhea/rhinorrhea	0.5	0.1–2.9	0.5671
Sex (female vs male)	1.1	0.6–2.1	0.6671
Vascular injury	1.7	0.9–3.0	0.1061
Vault fracture	0.8	0.4–1.3	0.2805
Base fracture	1.5	0.8–3.1	0.2232

Boldface type indicates statistical significance.

meningitis in the first 90 days following the injury than patients without a CSF leak. The presence of rhinorrhea was much more predictive of future meningitis infection than otorrhea (OR 26.5 vs 7.1, respectively). Additionally, we found that closed skull base and open vault fractures were associated with high rates of CSF leak. In particular, skull base fractures with cerebral hemorrhage and laceration were strongly associated with CSF leak.

Patients with CSF leaks were also far more likely to require a neurosurgical intervention than patients without a leak (24.8% vs 9.6%), especially decompressive craniectomies (OR 6.0), EVDs (OR 4.2), and lumbar drains (OR 107.5). This discrepancy is similar to those previously reported^{7,20} and likely highlights the increased risks associated with CSF leak, including encephalitis and growing pneumocephalus.^{1,13} The nature of the data does not allow us to draw conclusions about the causality of the found associations, however, and the high rate of CSF leaks in the identified populations at risk might also be a result rather than a cause of treatment. Patients who ended up developing a CSF leak may have suffered from more severe injuries, requiring decompressive craniectomies to manage brain edema or EVD placement to relieve intracranial hypertension from swelling or associated posttraumatic hydrocephalus. Those are conditions with an intrinsic risk for CSF leaks. In support of this hypothesis, we observed a significantly higher rate of vascular injury in the CSF leak population than in the general cohort (60.9% vs 40.7%, $p < 0.0001$). Still, the vast majority of patients with CSF leaks (75.2%) did not receive a neurosurgical procedure, echoing past studies that reported high rates of spontaneous CSF leak resolution or resolution with drainage and acetazolamide treatment.¹³ When rates of neurosurgical intervention in patients with CSF leaks were stratified by fracture location, it was observed that only 23.9% ($n = 42$) of patients with closed skull base fractures underwent an operation. This is contrasted with 69.2% ($n = 9$) of patients with open vault fractures, though the different sample sizes limit definitive comparisons.

The healthcare costs associated with pediatric skull fracture patients with CSF leaks have not been well documented in the literature.^{6,21} Traumatic CSF leaks are as-

sociated with greater hospital and physician expenditures, both at the index hospitalization and at 90 days. However, since average LOSs were longer in the CSF leak cohort than in the non-CSF leak cohort, it is possible that the difference in costs is largely attributable to prolonged admission,^{6,21} especially in the intensive care unit. The increased rates of neurosurgical procedures for patients with CSF leaks are also likely contributors to the elevated costs associated with their care. Finally, patients with CSF leaks who develop meningitis or neurological deficits require significantly more resources, thus driving up average costs for the entire cohort. Further cost analyses stratified by comorbidities and LOS are needed to more precisely characterize the cost discrepancies between pediatric skull fracture patients with CSF leaks and those without CSF leaks.

Between 2007 and 2015, skull fracture admissions declined by more than 40% and the average LOS decreased by 19%, yet costs still increased by roughly 20%. The inverse relationship between LOS and cost is concerning and without obvious explanation. While a majority of pediatric patients with skull fractures are aggressively managed and admitted at high rates,¹⁵ there is little extant data on longitudinal treatment trends. Notably, the majority of the cost increase occurred after 2010, which coincided with the passage and implementation of major healthcare reform. Further investigation is needed to determine how much of the cost increase is due to the general rise in healthcare prices versus more specific skull fracture-related treatment paradigms.

Over the past decade, numerous reports have indicated that a majority of CSF leaks resolve spontaneously and do not require surgical intervention. While CSF leaks are rare after pediatric skull fractures, they are associated with significant morbidity, including meningitis and neurological deficits. Close clinical surveillance is required for this population, particularly those with multiple fractures or closed basilar skull fractures. Given the increased risk of adverse outcomes in patients with CSF leaks, we suggest further investigation to determine whether or not more aggressive treatment—including early drainage, decompression, or prophylactic antibiotic treatment—may be warranted.

Limitations

As with all large database studies, interpretations of this study are limited by the administrative nature of the data. We assumed the accuracy of all diagnosis and procedure codes in the database. The MarketScan database aggregates data on commercially insured patients. Because patients, procedures, and clinical outcomes were queried using ICD-9-CM codes, it is not possible to assess the underlying validity of the collected records. Additionally, potential questions and analyses are constrained by the specificity of the ICD codes. For example, ICD codes do not include depressed or growing skull fractures, specific bones fractured, or antibiotics used, and, therefore, their specific associations with rates of CSF leak and meningitis risk could not be explored. The severity of the disease is also not discernable in MarketScan data. Finally, because the MarketScan database only covers insured patients, this

study has substantial selection bias against uninsured pediatric patients with skull fractures. Lack of insurance has been previously implicated in longer hospitalizations²⁶ and lower readmission rates¹⁶ for patients with skull fractures. Unfortunately, this could not be assessed in the current study.

Conclusions

We found that CSF leaks occurred in 1.46% of pediatric patients with skull fractures, and the leaks were associated with significantly increased rates of neurosurgical intervention and risks of meningitis, hospital readmission, and neurological deficits at 90 days. In particular, patients with CSF rhinorrhea were much more likely to develop meningitis than patients with otorrhea, but vascular injury, sex, and base or vault fractures were not predictive factors. Pediatric patients with skull fractures also experienced a longer average LOS and greater healthcare costs at presentation and at 90 days. Further studies should investigate the risk factors of developing a CSF leak following skull fracture, the role of surgical intervention in its management, and the benefit of prophylactic antibiotics.

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Disclosures

Dr. Veeravagu reports being a consultant for NuVasive, Medtronic, and Surgical Theater.

Author Contributions

Conception and design: Veeravagu, Varshneya, Rodrigues, Medress. Acquisition of data: Varshneya, Rodrigues, Medress. Analysis and interpretation of data: Varshneya, Rodrigues, Medress. Drafting the article: Varshneya, Rodrigues, Stienen, Grant. Critically revising the article: Veeravagu, Varshneya, Rodrigues, Stienen, Grant. Reviewed submitted version of manuscript: Varshneya, Rodrigues, Medress, Stienen, Grant, Ratliff. Statistical analysis: Veeravagu, Varshneya. Administrative/technical/material support: Veeravagu, Rodrigues, Medress, Grant, Ratliff. Study supervision: Veeravagu, Medress, Stienen, Grant, Ratliff.

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