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Article

Association Between Skull Base Fracture Location and Likelihood of Developing a Traumatic CSF Leak

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ABSTRACT

Background: Skull base fractures (SBFs) pose a significant risk for traumatic cerebrospinal fluid (CSF) leaks, which can lead to serious complications if undetected. Despite anatomical correlations, the predictive value of fracture location on CSF leak development remains inadequately explored in contemporary clinical settings. **Objective**: To evaluate the association between specific skull base fracture locations (anterior, middle, posterior) and the likelihood of developing a traumatic CSF leak in adult head-injured patients. **Methods**: This cross-sectional observational study was conducted at the Neurosurgery Department of Shaheed Mohtarma Benazir Bhutto Institute of Trauma (SMBBIT), Karachi, from July to December 2024, including 200 patients with radiographically confirmed skull base fractures. Adults over 18 years were included, excluding those with pathological, surgical, or congenital causes of CSF leaks. Clinical diagnosis of CSF rhinorrhea or otorrhea was supported by bedside glucose testing, and fracture location was confirmed via CT/MRI. Ethical approval was obtained, and all participants provided informed consent per the Declaration of Helsinki. Statistical analyses were conducted using SPSS v25, employing chi-square tests, Pearson correlation, and linear regression to assess associations. **Results**: CSF leaks occurred in 10% of cases, predominantly in anterior fractures (12/75), but the chi-square test showed no statistically significant association ($p = 0.118$). Regression analysis revealed fracture location ($\beta = -0.234$, $p = 0.005$) and gender ($\beta = -0.180$, $p = 0.030$) as significant predictors, while age was not. **Conclusion**: Although anterior skull base fractures were more frequently associated with CSF leaks, fracture location alone did not predict leakage in univariate analysis. Gender and anatomical site, however, emerged as significant predictors in multivariate modeling. These findings support a multifactorial risk assessment approach to enhance early CSF leak detection and improve outcomes in head trauma management.

Keywords: Skull Base Fracture, Cerebrospinal Fluid Leak, Head Trauma, CSF Rhinorrhea, Otorrhea, Anterior Cranial Fossa, Traumatic Brain Injury

INTRODUCTION

Skull base fractures (SBFs) constitute a significant subset of traumatic head injuries and present a notable risk of cerebrospinal fluid (CSF) leaks, a complication that can lead to serious morbidity if not promptly recognized and managed. These fractures, which account for approximately 21% of all skull fractures, are known to involve the anterior, middle, and posterior cranial fossae, each varying in their anatomical predisposition to CSF leakage (1). Historical data estimate CSF leak incidence between 10% and 30% among patients with skull base fractures; however, more recent institutional analyses suggest a declining trend, with some large cohort studies reporting incidences as low as 4% (2). This reduction may be attributed to advances in imaging modalities, improved trauma care, and early conservative management practices. Despite the downward trend, CSF leakage remains a clinically important issue, particularly when it arises from fractures involving anatomically vulnerable structures such as the cribriform plate and temporal bone.

The anterior cranial fossa (ACF), due to its relatively thin bony architecture and proximity of the dura mater to the bone surface, is often implicated in CSF rhinorrhea, where a direct communication between the subarachnoid space and nasal cavity facilitates fluid escape (3). Reports suggest that anterior skull base fractures may account for up to 50% of all traumatic CSF leaks (4). In contrast, fractures in the middle cranial fossa, particularly those affecting the temporal bone, are frequently associated with CSF otorrhea. Longitudinal fractures, being the most common type in this region, may breach the dura and tympanic membrane, allowing CSF to enter the middle ear (6). Although less commonly affected, posterior cranial fossa fractures can also result in CSF leaks, albeit rarely, due to the inherently robust bony protection and the anatomical positioning of the cerebellum and brainstem (8).

Existing literature has emphasized anatomical location as a determinant for both the likelihood and clinical manifestation of CSF leakage. Nonetheless, this relationship is not absolute, and varying frequencies and types of CSF leak presentations suggest a complex interplay of factors beyond fracture location alone (11). While anterior skull base injuries are typically associated with rhinorrhea and middle fossa injuries with otorrhea, not all patients with fractures in these regions go on to develop CSF leaks, highlighting the need to investigate additional contributing variables.

Despite significant attention given to the anatomical correlates of traumatic CSF leakage, literature remains limited in clearly delineating predictive associations that can reliably inform clinical risk stratification. In particular, there is a paucity of data examining whether fracture location can serve as an independent predictor for CSF leak occurrence. Furthermore, the potential influence of demographic variables such as age and gender has not been thoroughly explored. Some retrospective analyses suggest gender-based differences in risk, while others find no such association (16). The ambiguity in current evidence necessitates further investigation to clarify the potential roles of these variables in CSF leak pathophysiology.

Given this context, the present study was designed to evaluate the association between skull base fracture location and the incidence of traumatic CSF leaks in patients presenting with head trauma. By integrating imaging findings, demographic data, and clinical presentations, this study aims to clarify whether specific anatomical fracture patterns are significantly predictive of CSF leakage. Additionally, the analysis explores the possible influence of age and gender on leak development. The overarching research question guiding this inquiry is: *Does the anatomical location of a skull base fracture significantly influence the likelihood of developing a traumatic CSF leak in head-injured patients?*

MATERIAL AND METHODS

This cross-sectional observational study was conducted at the Department of Neurosurgery, Shaheed Mohtarma Benazir Bhutto Institute of Trauma Center (SMBBIT), Karachi, over a six-month period from July 1, 2024, to December 31, 2024. A total of 200 patients were included through non-probability consecutive sampling. Eligibility criteria comprised adult patients above 18 years of age of both genders who sustained skull base fractures following traumatic head injury confirmed by radiographic imaging (CT or MRI). Patients were excluded if they had pre-existing conditions known to cause CSF leaks, such as congenital cranial defects or intracranial tumors, or if the skull base fractures were pathological or iatrogenic in origin (e.g., post-surgical or procedural complications). Informed consent was obtained from all participants prior to enrollment, and confidentiality of patient data was maintained throughout the study. The study was conducted in accordance with the ethical standards of the Declaration of Helsinki.

All participants underwent initial imaging assessments (CT and/or MRI) to confirm the presence and location of skull base fractures, which were categorized anatomically as anterior, middle, or posterior cranial fossa fractures. The primary outcome was the occurrence of CSF leakage, clinically defined by the presence of clear nasal discharge (rhinorrhea) or ear discharge (otorrhea). Suspected CSF fluid was analyzed bedside using CSF glucose testing to support the diagnosis. Secondary outcomes included the anatomical pattern of fracture and its association with CSF leak, as well as demographic factors such as age and gender. All patients were monitored for up to five days during their hospital stay for clinical signs of CSF leakage. Those with extended admissions due to polytrauma were followed during hospitalization, and stable patients were followed up for a maximum period of one month. No patients were kept admitted beyond the standard period of observation solely for study purposes.

Data were entered and analyzed using SPSS version 25. Descriptive statistics were applied to summarize demographic and clinical characteristics. A chi-square test was conducted to assess the association between fracture location and CSF leak occurrence. Pearson correlation analysis was performed to evaluate the relationship between age and CSF leak. Linear regression analysis was used to determine the effect of age, gender, and fracture location on the likelihood of developing CSF leakage. A p-value less than 0.05 was considered statistically significant in all analyses.

RESULTS

A total of 200 patients with radiologically confirmed skull base fractures were included in the analysis. The mean age of the study population was 53.15 ± 22.18 years. Among these patients, 91 (46%) were male and 109 (54%) were female. Fracture distribution across the cranial fossae showed 75 cases (38%) involving the anterior skull base, 66 cases (33%) affecting the middle fossa, and 59 cases (30%) involving the posterior fossa. The overall incidence of cerebrospinal fluid (CSF) leakage was 10% (n = 20). Rhinorrhea was reported in 12 patients (6%), while 8 patients (4%) presented with otorrhea.

A chi-square test was performed to examine the association between fracture location and CSF leak occurrence. While anterior skull base fractures were associated with the highest number of CSF leaks (n = 12), followed by both middle and posterior fossa fractures (n = 4 each), the overall association did not reach statistical significance ($\chi^2 = 4.302$, df = 2, $p = 0.118$), indicating that fracture location alone may not be a reliable predictor of CSF leakage. Pearson correlation analysis revealed no significant relationship between patient age and the occurrence of CSF leakage ($r = -0.056$, $p = 0.435$). This finding suggests that age is not a contributing factor in the development of traumatic CSF leaks

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among patients with skull base fractures. To assess the influence of multiple independent variables—age, gender, and fracture location—on the occurrence of CSF leak, a linear regression analysis was performed. The model was statistically significant overall ($p < 0.001$). Age was not a significant predictor (β = -0.001, $p = 0.257$), whereas gender and fracture location were both significantly associated with CSF leak occurrence. Specifically, males were found to be significantly less likely to develop CSF leaks compared to females (β = -0.180, $p = 0.030$). Fracture location also showed a statistically significant relationship with CSF leakage (β = -0.234, $p = 0.005$), suggesting anatomical site plays a contributory, though not independently predictive, role. Despite the lack of statistical significance in the chi-square test, the regression model suggests that gender and fracture location, when adjusted for other variables, may be important factors influencing CSF leak development.

Table 1: Demographic and Clinical Characteristics of the Study Population (N = 200)

Variable	Mean ± SD / Frequency (%)
Age (years)	53.15 ± 22.18
Gender (Male)	91 (46%)
Gender (Female)	109 (54%)
Fracture Location	
• Anterior	75 (38%)
• Middle	66 (33%)
• Posterior	59 (30%)
CSF Leak	20 (10%)
• Rhinorrhea	12 (6%)
• Otorrhea	8 (4%)

Table 2: Association Between Fracture Location and CSF Leak (Chi-Square Test)

Fracture Location	CSF Leak (Yes)	CSF Leak (No)	p-value
Anterior	12	63	
Middle	4	61	
Posterior	4	55	0.118

Table 3: Correlation Between Patient Age and CSF Leak (Pearson Correlation)

Variables	CSF Leak	Age
CSF Leak	1	-0.056
Age	-0.056	1
Significance (2-tailed)	–	0.435
N	200	200

Table 4: Linear Regression Analysis for Predictors of CSF Leak

Predictor	Standardized β	SE	t	p-value	95% CI (Lower, Upper)
Constant	–	0.126	3.757	<0.001	0.225, 0.723
Age	-0.001	0.001	-1.136	0.257	-0.003, 0.001
Gender (Male = 1)	-0.180	0.051	-2.191	0.030	-0.212, -0.011
Fracture Location	-0.234	0.029	-2.855	0.005	-0.141, -0.026

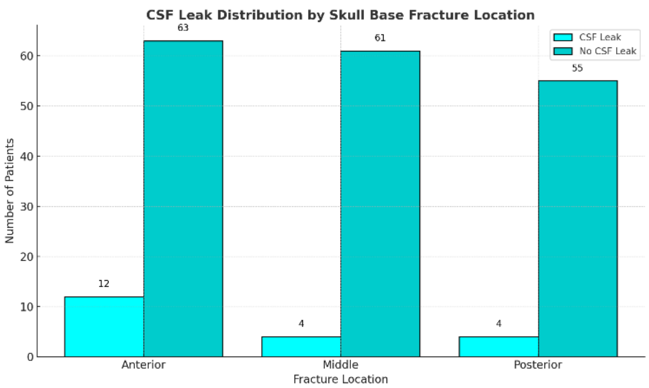

Figure 1 CSF Leak Location Pattern

These findings indicate that although fracture location is not independently predictive of CSF leaks when considered alone, its significance emerges in a multivariate context. Moreover, female patients demonstrated a higher risk for CSF leakage, an observation warranting further investigation to determine underlying anatomical or physiological contributors.

DISCUSSION

The findings of this study contribute to the growing body of evidence regarding the anatomical and demographic factors associated with cerebrospinal fluid (CSF) leakage following skull base fractures (SBFs). With an observed CSF leak incidence of 10%, this study aligns with earlier estimates ranging from 10% to 30%, although more recent institutional data have reported lower rates, possibly due to improved trauma care and diagnostic imaging techniques (1,2). This moderate leak rate suggests that while the occurrence is not uncommon, it may be underdiagnosed

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without systematic surveillance in patients with confirmed skull base trauma.

Consistent with existing literature, the majority of CSF leaks in this study were associated with anterior skull base fractures, followed by middle and posterior fossa fractures (3,4). Anatomically, this trend is explainable by the thin bony structures of the anterior cranial fossa and the close proximity of the dura to fracture-prone areas such as the cribriform plate and ethmoid bone, facilitating direct communication between intracranial and extracranial compartments (5). However, despite the numerical predominance of CSF leaks in anterior fractures, the chi-square analysis did not demonstrate a statistically significant association between fracture location and CSF leak occurrence ($p = 0.118$). This contrasts with systematic reviews that have previously emphasized a stronger link between anterior fractures and CSF rhinorrhea (3,14), suggesting that while location is an important factor, it may not serve as an independent predictor without consideration of fracture severity, displacement, or associated dural tears.

Interestingly, the regression analysis provided a more nuanced interpretation by revealing that when controlling for age and gender, fracture location did significantly influence the likelihood of CSF leakage ($\beta = -0.234$, $p = 0.005$). This suggests that multivariate models may offer more precise risk estimations compared to univariate approaches. Furthermore, gender emerged as a significant predictor, with males demonstrating a lower likelihood of CSF leak development ($\beta = -0.180$, $p = 0.030$). While previous trauma database analyses have shown higher overall SBF rates among males, especially in high-velocity trauma cases (16), our findings challenge the assumption that male sex confers a higher risk of CSF leak. This divergence could reflect gender-related anatomical or hormonal differences, or behavioral factors influencing presentation and diagnosis, but warrants further investigation.

The lack of significant correlation between patient age and CSF leak ($r = -0.056$, $p = 0.435$) suggests that age alone is not a determinant of leakage risk, a finding supported by other retrospective analyses that have not established age as a standalone factor (15). From a clinical perspective, this highlights the importance of focusing on anatomical and injury-related variables over demographic features when stratifying risk and planning follow-up care.

The clinical implications of these findings are considerable. Early detection and management of CSF leaks are essential to prevent complications such as meningitis, pneumocephalus, and prolonged hospitalization. Understanding the anatomical predisposition can assist neurosurgeons and trauma teams in identifying high-risk cases and implementing targeted monitoring strategies. The results also underscore the utility of combining imaging findings with clinical vigilance and point-of-care testing (e.g., bedside glucose testing of nasal or ear discharge) for timely diagnosis. Moreover, the finding that fracture location may influence CSF leak risk only when considered alongside other variables supports the need for integrated assessment models rather than reliance on isolated factors.

Despite these contributions, the study has several limitations that should be acknowledged. The sample size, while adequate for initial estimation, may limit the generalizability of the findings, particularly in detecting smaller effect sizes. Additionally, the single-center design and reliance on non-probability sampling may introduce selection bias. Although imaging confirmation was employed for fracture localization, interobserver variability in radiological interpretation was not assessed. Moreover, the relatively short follow-up duration may have missed delayed CSF leaks, a known clinical phenomenon. The use of bedside biochemical tests for CSF confirmation, while practical, may lack sensitivity compared to β2-transferrin assays, potentially affecting diagnostic accuracy.

Future research should aim to validate these findings through multicenter studies with larger and more diverse populations. Incorporating advanced imaging, such as CT cisternography or high-resolution MRI, and employing more sensitive biochemical markers could enhance diagnostic precision. Further exploration into the role of fracture displacement, dural integrity, and patient-specific anatomical features will be vital to developing robust predictive models. Investigating the biological mechanisms underlying gender differences in CSF leak risk may also offer new insights into personalized care strategies.

In conclusion, this study reinforces the clinical observation that anterior skull base fractures are more frequently associated with CSF leaks, although their predictive value may be limited when evaluated in isolation. The findings support the integration of anatomical, demographic, and injury-related data in assessing CSF leak risk. By highlighting key predictive variables, this research contributes to improved identification and management of CSF leaks in the context of traumatic skull base fractures, while also pointing to the need for further investigations to refine clinical decision-making frameworks.

CONCLUSION

This study evaluated the association between skull base fracture location and the likelihood of developing traumatic cerebrospinal fluid (CSF) leaks, revealing that anterior skull base fractures were the most commonly associated with CSF leakage, although the location alone did not independently predict leak occurrence in univariate analysis. However, multivariate analysis identified both fracture location and gender as significant factors influencing CSF leak risk, with males being less likely to develop leakage. These findings underscore the importance of integrated risk assessment beyond anatomical site alone and highlight the need for heightened clinical vigilance in anterior skull base trauma. The results have direct implications for improving early detection, monitoring strategies, and individualized management plans in head-injured patients. Future research should focus on refining predictive models using larger, multicenter datasets and advanced diagnostics to guide evidence-based interventions for preventing CSF leak-related complications in neurotrauma care.

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