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Original Article

Zygomatic fracture characteristics and their association with brain injury: Evidences from a 10-year retrospective study in northern Taiwan

Wei-Che Tsai [a†], Chen-Yin Yong [a†], Sam Li-Sheng Chen [b,c], Yoichi Ohiro [d], Chih-Yuan Fang [a,b*]

[a] Department of Oral Medicine, Wan Fang Hospital, Taipei Medical University, Taipei, Taiwan
[b] School of Dentistry, College of Oral Medicine, Taipei Medical University, Taipei, Taiwan
[c] Department of Oral Medicine, Taipei Medical University-Shuang Ho Hospital, Ministry of Health and Welfare, New Taipei City, Taiwan
[d] Oral and Maxillofacial Surgery, Division of Oral Pathobiological Science, Faculty of Dental Medicine and Graduate School of Dental Medicine, Hokkaido University, Sapporo, Japan

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KEYWORDS
Brain injury;
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Abstract *Background/purpose:* Few studies have systematically examined the relationship between zygomatic fracture patterns or patient demographics and head injury. This study investigates the epidemiology of zygomatic fractures, their association with brain injury, and the influence of patient age, focusing on fracture classification and injury mechanisms.
Materials and methods: A retrospective analysis of 272 patients with zygomatic fractures treated between 2012 and 2021 at a medical center in northern Taiwan was conducted. Fractures were classified using the Zingg system. Clinical data including age, injury etiology, concomitant injuries, and brain injury were analyzed. Statistical methods included chi-square tests, one-way ANOVA, and multiple logistic regression.
Results: Motorcycle accidents were the most common cause of zygomatic fractures (43.4 %), followed by falls (27.9 %). The highest incidence occurred in patients aged 61–70 years. Older patients had significantly lower surgical intervention rates ($P < 0.05$). Type B fractures were most common (51.8 %), and bilateral fractures were significantly associated with higher rates of brain injury (58.3 % vs. 26.6 %, $P < 0.05$). Among patients with fall-related

* Corresponding author. Department of Oral Medicine, Wan Fang Hospital, Taipei Medical University, No. 111, Sec. 3, Xinglong Road, Wenshan District, Taipei 116081, Taiwan.
E-mail addresses: 100044@w.tmu.edu.tw, d204106002@tmu.edu.tw (C.-Y. Fang).
† Wei-Che Tsai and Chen-Yin Yong contributed equally to this article.

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fractures, those with brain injury were significantly older than those without ($P = 0.008$). Even low-energy trauma, such as ground-level falls, led to brain injury in elderly patients. In younger individuals, brain injury was associated with bilateral fractures and concomitant injuries, whereas in older patients, age itself was a major risk factor for brain injury.
Conclusion: Falls are increasingly associated with zygomatic fractures in older adults, and even minor trauma can result in brain injury. Bilateral fractures and high-energy mechanisms remain key predictors of brain injury in younger patients.

Introduction

The zygomatic bones, located on both sides of the midface, articulate with the frontal, maxillary, temporal, and sphenoid bones, forming the prominence of the cheeks and the lateral portion of the orbital rim.[1] Beyond their role in midfacial structure, the zygomatic bones contribute significantly to both the strength of the craniofacial skeleton and overall facial appearance. Due to their prominent anatomical position, zygomatic fractures are common in high-energy impacts such as traffic accidents, falls, and physical assaults.[1,2] Depending on the mechanism, impact location, and energy transfer, these fractures may occur in isolation or in combination with other serious injuries, including brain, spinal, or systemic trauma.[1,3] Displaced zygomatic fractures can lead to facial deformity, sensory deficits in the paranasal region, diplopia, or visual impairment, often necessitating surgical intervention. Accurate anatomical reduction is essential to restore facial projection, facial width, and orbital volume, thereby achieving both functional and aesthetic outcomes.[4] Inadequate reduction may result in persistent facial asymmetry, infraorbital nerve dysfunction, ocular complications, or restriction of mandibular movement.[5]

The epidemiology and causes of zygomatic fractures vary across populations and continue to evolve due to differences in trauma mechanisms and environmental factors.[6—8] To facilitate diagnosis and guide surgical management, several classification systems have been proposed. One widely adopted system is the Zingg classification,[6] which categorizes zygomatic fractures based on anatomical involvement. Type A fractures are limited to a single site of the zygoma: A1 involves the zygomatic arch, A2 the lateral orbital rim, and A3 the inferior orbital rim. Type B fractures disrupt all four suture lines of the zygoma, while Type C fractures are characterized by comminution. Due to the zygoma's anatomical proximity to the brain, concerns have been raised regarding the risk of concomitant brain injuries in patients with zygomatic fractures. Nevertheless, few studies have systemically examined how specific fracture patterns or patient demographics influence this risk. To address this gap, we conducted a retrospective analysis using the Zingg classification to investigate the epidemiology of zygomatic fractures and their association with brain injury.

Materials and methods

Demographic and geographical characteristics

This retrospective study was approved by the Institutional Review Board of Taipei Medical University Hospital (Approval No. TMU-JIRB 202304038) and conducted at Wan Fang Hospital in Taipei, Northern Taiwan. The hospital primarily serves a population of approximately 250,000 to 260,000 residents in the surrounding area, which includes five universities, two high schools, a military base, a metro station, and several large residential communities.[9] The region's complex road networks and high prevalence of motorcycle use contribute to an increased risk of facial trauma and variability in fracture patterns. These demographic and environmental factors create a diverse patient population, making the area suitable for investigating fracture epidemiology and injury mechanisms.

Data collection

Patients with zygomatic fractures, with or without additional fractures at other anatomical sites, who received treatment between January 1, 2012, and December 31, 2021, were included in this study. Patients with incomplete medical records or missing computed tomography (CT) images were excluded. Data collected included age, sex, cause of injury (categorized as fall from height, ground-level fall, motorcycle accident, motor vehicle accident, bicycle accident, or blunt trauma from an object), presence of head injury, and fractures involving the extremities or other facial bones.

Zygomatic fractures were assessed by two oral and maxillofacial surgeons and one senior resident using medical records and CT images. Prior to the formal image interpretation, a consensus meeting was conducted involving all three surgeons. During this meeting, five pilot cases with X-ray images were jointly reviewed to establish consistent diagnostic criteria. Subsequently, CT images of 272 patients were jointly reviewed by the senior resident and an attending surgeon. In cases where a definitive diagnosis could not be reached, the other experienced attending oral and maxillofacial surgeon was consulted to assist in reaching a consensus classification. Fractures were classified according to the Zingg classification system into the following categories: A1 (zygomatic arch), A2 (lateral orbital rim), A3 (inferior orbital rim), B (tetrapod fractures involving all four suture lines), or C (comminuted fractures). The representative CT images for the zygomatic fractures of the study were illustrated as Supplemental Fig. 1. Additional fracture sites were categorized as 1) other facial fractures or 2) fractures of the extremities and trunk. Patients were identified using ICD-9 and ICD-10 diagnostic codes for zygomatic fractures from the hospital database. In total, 272 patients with 296 zygomatic fracture sites were included. Fourteen patients were excluded from the etiology analysis due to unavailable injury cause data, and 19 patients with unspecified traffic accident causes were grouped separately. As all image classifications were determined through consensus, inter-rater agreement analysis (e.g., Cohen's or Fleiss' kappa) was not performed.

Statistical analyses

Fisher's exact test was used to assess categorical variables when group sizes were small. Multiple logistic regression was applied to examine the association between zygomatic fracture classification and the occurrence of brain injury. A *P*-value of less than 0.05 was considered statistically significant.

Results

Fig. 1 presents the age distribution of the patients in this study. A total of 272 patients with zygomatic fractures were included, consisting of 178 males and 94 females (male-to-female ratio: 1.89:1). The mean age was 49.6 years (range: 15–97 years). The highest incidence of zygomatic fractures occurred among individuals aged 61–70 years ($n = 50$), followed by the 21–30 years and 51–60 years age groups ($n = 43$ each). After excluding 14 patients with unknown injury causes, road traffic accidents (RTAs) were identified as the leading cause of zygomatic fractures, accounting for 68.99 % (178/258) of cases.

As presented in Fig. 2, motorcycle accidents were the most common mechanism (43.41 %), followed by motor vehicle collisions (13.18 %), bicycle accidents (5.04 %), and unspecified RTAs (7.36 %). Fall-related injuries were the second most frequent cause (27.91 %; 72/258), including falls from standing level and falls from height (1.94 %). Blunt trauma from objects accounted for a small proportion of injuries (1.16 %). The overall prevalence of concomitant brain injury was 29.4 % (80/272).

Fractures were classified according to the Zingg system, with type B fractures being the most prevalent (Fig. 3). Regarding fracture severity, 18.0 % (49/272) of patients had single-process displacement, 15.4 % (42/272) had two-process displacement, 36.4 % (99/272) had tripod fractures, 21.3 % (58/272) had comminuted fractures, and 8.8 % (24/272) sustained bilateral zygomatic fractures. Type B fractures were the predominant pattern across all injury mechanisms (Fig. 4); however, no statistically significant association was found between fracture pattern and injury etiology ($P = 0.56$). Further analysis of injury mechanisms by age demonstrated that RTAs were the predominant cause of zygomatic fractures among individuals aged 60 years and below. In contrast, falls emerged as the leading cause among patients over 60 years of age ($P < 0.001$) (Fig. 5).

Surgical intervention rates declined significantly with increasing age. The highest proportion of surgical treatment was observed in the 41–50 years age group, with 68.8 % (22/32) undergoing surgery, whereas none of the patients over 91 years of age (0/5) received surgical management (Fig. 6). Linear regression analysis confirmed a significant inverse correlation between age and surgery rate ($P < 0.05$) (Fig. 7).

One-way ANOVA demonstrated a statistically significant difference in mean age between patients with fall-related injuries who had concomitant brain injury and those without brain injury ($F(1, 70) = 7.54$, $P = 0.008$) (Table 1). Specifically, patients with brain injuries had a higher mean

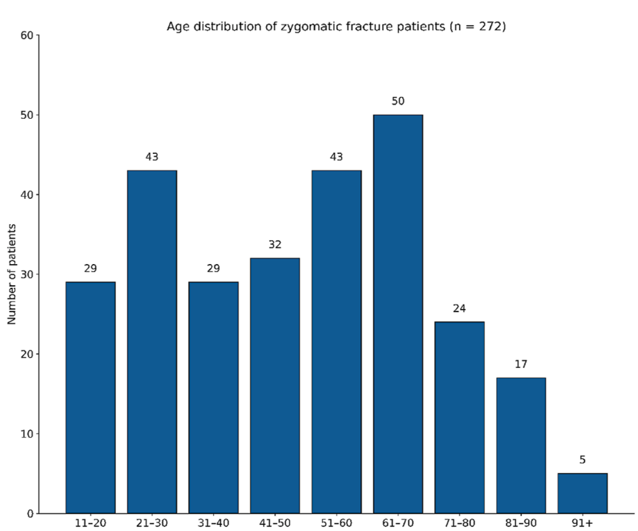

Fig. 1 Age distribution of patients with zygomatic fractures ($n = 272$).

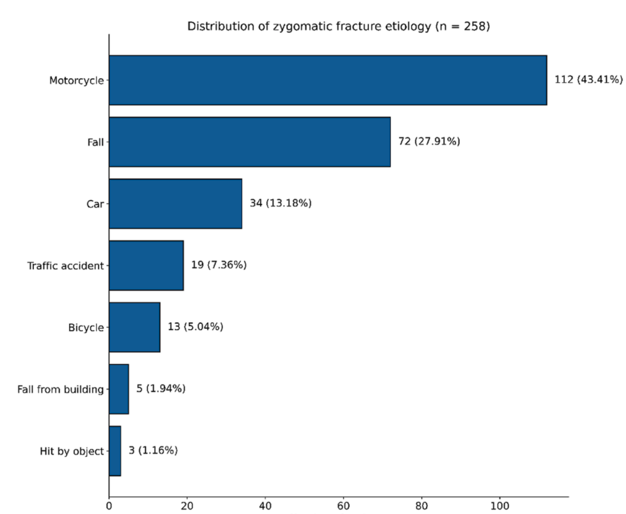

Fig. 2 Distribution of fracture etiology, with motorcycle accidents as the leading cause ($n = 258$).

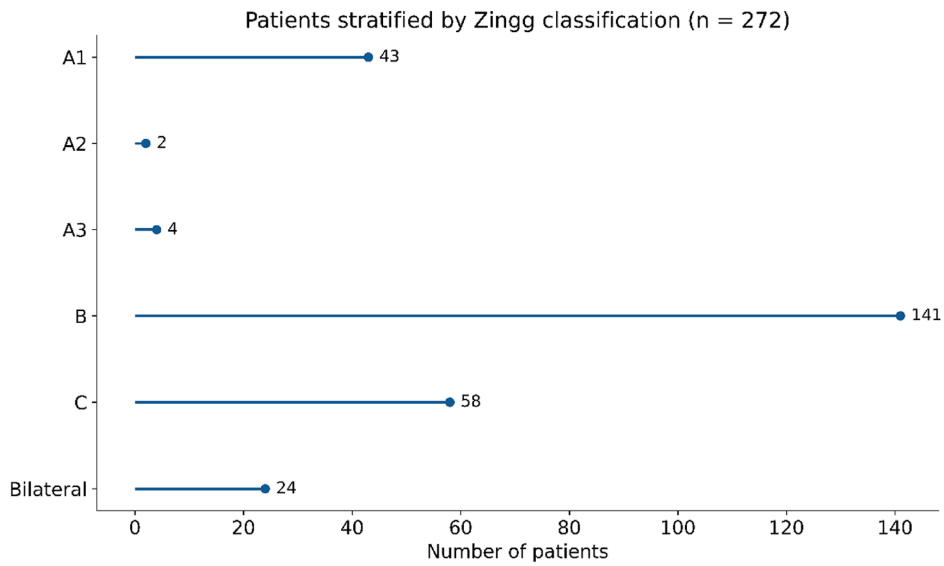

Fig. 3 Patients stratified by Zingg classification, showing the absolute frequency of each subtype (n = 272). A1: The fracture line involves the zygomatic arch. A2: The fracture line involves the lateral orbital rim. A3: The fracture line involves the inferior orbital rim. B: The fractures disrupt all four suture lines of the zygoma. C: The fractures are characterized by comminution. Bilateral: The fractures involved bilateral zygoma.

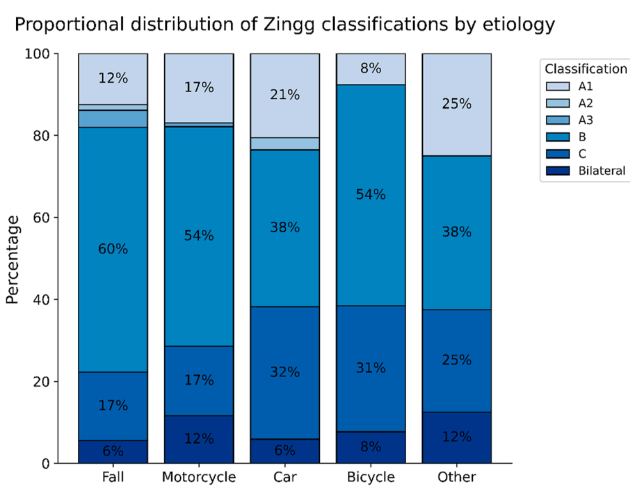

Fig. 4 Proportional distribution of Zingg classifications by etiology, normalized to 100% within each cause category.

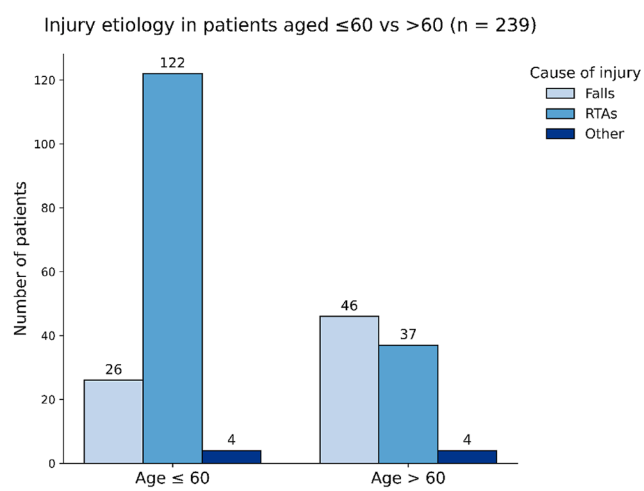

Fig. 5 Injury etiology stratified by age group (≤60 vs >60 years). Road traffic accidents (RTAs) were the predominant cause in younger patients, while falls were more frequent in older patients.

age of 76.6 years (SD ≈ 14.5) compared to 63.0 years (SD ≈ 17.0) in those without brain injuries, indicating that older individuals are at increased risk of sustaining brain injury following a fall.

Additionally, fracture pattern was significantly associated with the occurrence of brain injury ($P < 0.05$) (Table 2), with bilateral zygomatic fractures demonstrating a significantly higher likelihood of brain injury compared to unilateral fractures.

We also performed an age-stratified analysis to further explore the relationship between fracture patterns and brain injury, using 60 years as the cutoff. Among patients aged 60 years and younger, brain injury demonstrated a marginal association with type A zygomatic fractures and was significantly associated with concomitant fractures and bilateral fractures (Table 3). In contrast, among patients over 60 years of age, no significant association was observed between fracture patterns and the occurrence of brain injury (Table 4).

These findings suggest two distinct mechanisms underlying brain injury in patients with zygomatic fractures. In younger individuals, brain injury is primarily associated with high-energy impacts resulting in complex fractures and concomitant injuries. In older patients, brain injury is often observed following low-energy trauma, including simple ground-level falls, highlighting that even minimal-impact incidents can lead to significant intracranial injury in this population.[10]

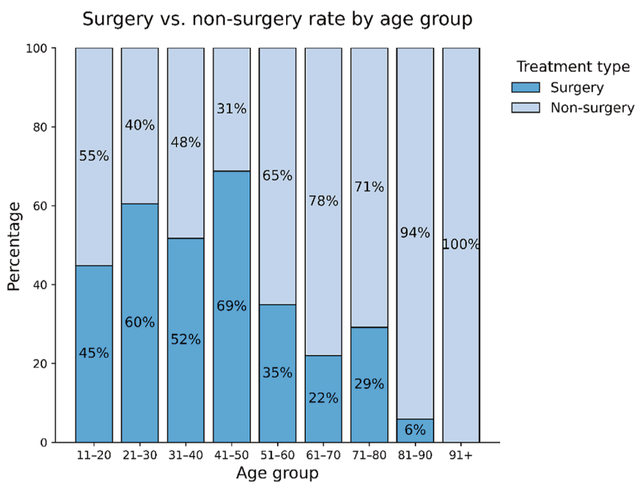

Fig. 6 Percentage of patients receiving surgery or not, categorized by age group. Older patients had progressively lower surgery rates.

Discussion

In this study, motorcycle accidents were the most frequent cause of zygomaticomaxillary complex (ZMC) fractures, followed by falls and motor vehicle collisions. This pattern is consistent with previous reports from Taiwan[9] and mirrors the etiology observed for mandibular fractures within the same population.[11] However, the leading causes of zygomatic fractures differ geographically. In European cohorts, interpersonal violence has been reported as the primary cause,[12] highlighting the influence of regional and cultural factors on fracture epidemiology.

The highest incidence of zygomatic fractures in our cohort occurred among individuals aged 61—70 years, followed by those aged 21—30 years. This finding contrasts with prior studies on mandibular fractures, where the peak incidence was among younger adults aged 21—30 years.[11] The increased incidence of zygomatic fractures in older individuals in our study was strongly associated with fall-related injuries, which accounted for over 50 % of

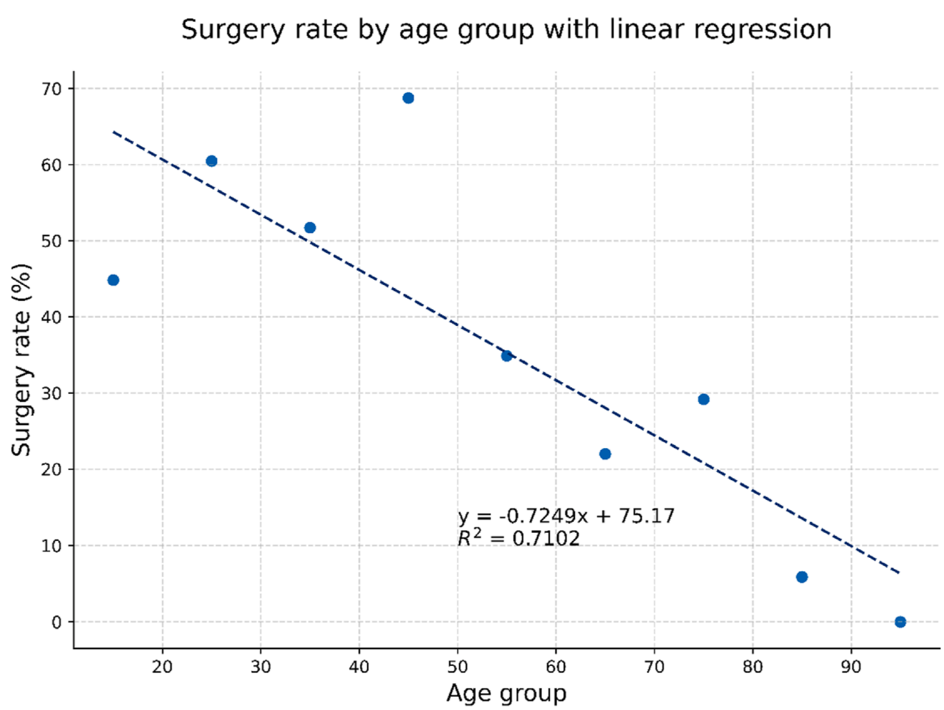

Fig. 7 Linear regression analysis showing a significant negative correlation between age and surgery rate ($P < 0.05$).

Table 1 Comparison of patient age between those with and without brain injuries in fall-related zygomatic fractures. Descriptive statistics for each group are shown alongside the results of a one-way ANOVA. Patients with brain injuries had a significantly higher mean age compared to those without brain injuries (F (1, 70) = 7.54, $P = 0.008$). Variance was comparable across groups. The critical F value at $\alpha = 0.05$ was 3.978.

Group	N	Sum	Mean age	Variance		
Brain injuries	14	1072	76.57142857	210.5714286		
No brain injuries	58	3656	63.03448276	288.5601936		
	SS	**df**	**MS**	**F**	***P*-value**	**Critical F**
Between	2066.640394	1	2066.640394	7.540376128	0.00766245	3.977779393
Within	19185.35961	70	274.0765658			
Total	21252	71				

Table 2 Relationship between brain injury, surgery rate, Zingg classification, and other concomitant fractures in patents with ZMC fractures.

	Brain injury (n = 80)	No brain injury (n = 192)	Number
Surgery	26 (23.64 %)	84 (76.36 %)	110
No-surgery	54 (33.33 %)	108 (66.67 %)	162
		$P = 0.08$	
Zingg classification			
Type A (n = 49)	18 (36.73 %)	31 (63.27 %)	49
Type B (n = 141)	37 (26.24 %)	104 (73.76 %)	141
Type C (n = 58)	11 (18.97 %)	47 (81.03 %)	58
Bilateral (n = 24)	14 (58.33 %)	10 (41.67 %)	24
		$P < 0.05$	
Concomitant fractures	24 (41.38 %)	34 (58.62 %)	58
No concomitant fractures	56 (26.17 %)	158 (73.83 %)	214
		$P < 0.05$	

Abbreviations: ZMC, zygomaticomaxillary complex. Type A: The fractures are limited to a single site of the zygoma. Type B: The fractures disrupt all four suture lines of the zygoma. Type C: The fractures are characterized by comminution. Bilateral: The fractures involved bilateral zygoma.

Table 3 Multiple logistic regression analysis of Zingg classification and other concomitant fractures associated with brain injury in patients aged <60 years.

	Coefficients	Standard error	Odds ratio	95 % Confidence interval		*P* value
				Lower limit	Upper limit	
Intercept	−1.457	0.242				
Type A ZMC fracture vs non-type A	0.867	0.448	2.380	0.989	5.727	0.053
Body fracture	0.826	0.398	2.283	1.046	4.981	0.038
Bilateral ZMC fracture vs unilateral fracture	1.462	0.527	4.314	1.535	12.126	0.006

Abbreviations: ZMC, zygomaticomaxillary complex.

Table 4 Multiple logistic regression analysis of Zingg classification and other concomitant fractures associated with brain injury in patients aged >60 years.

	Coefficients	Standard error	Odds ratio	95% confidence interval		*P* value
				Lower limit	Upper limit	
Intercept	−1.457	0.242				
Type A ZMC fracture vs non-type A	0.867	0.448	2.380	0.989	5.727	0.053
Body fracture	0.826	0.398	2.283	1.046	4.981	0.038
Bilateral ZMC fracture vs unilateral fracture	1.462	0.527	4.314	1.535	12.126	0.006

Abbreviations: ZMC, zygomaticomaxillary complex. Type A: The fractures are limited to a single site of the zygoma.

fractures among patients aged 60 years and above (Fig. 2A). These findings reflect a broader public health concern given the aging global population and highlight the importance of fall prevention strategies targeting older adults.

Older patients in our cohort exhibited significantly lower rates of surgical intervention for zygomatic fractures. This may reflect a reduced emphasis on aesthetic outcomes among elderly individuals or a clinical preference to avoid surgery in the absence of functional deficits, such as ocular complications or mandibular restriction. These findings align with clinical observations suggesting that treatment decisions in older patients are often driven by functional considerations rather than cosmetic concerns.

Zygomatic fractures were classified according to the Zingg system, with type B fractures being the most prevalent, followed by type C fractures. No significant association was observed between injury etiology and fracture classification. However, a significant relationship was identified between fracture patterns and the occurrence of brain injury. Bilateral zygomatic fractures were associated with a markedly higher incidence of brain injury (58.3 %) compared to unilateral fractures (26.6 %). This likely reflects the greater energy required to produce bilateral fractures, increasing the risk of concomitant intracranial trauma.

Interestingly, among patients with unilateral fractures, the highest incidence of brain injury was observed in those with type A fractures, whereas type C fractures, despite being more severe and comminuted, were associated with the lowest incidence of brain injury (Table 1). This finding contrasts with conventional assumptions that more extensive or fragmented fractures should correlate with higher rates of intracranial injury. One possible explanation is that the anatomical structure of the zygomatic bone, particularly its curved and thin morphology, may absorb and dissipate impact forces, thereby reducing the transmission of energy to adjacent cranial structures.[13] Alternatively, in some high-energy impacts, the primary force vector may be directed toward the cranial vault rather than the midface, resulting in brain injury without necessarily causing extensive fragmentation of the zygomatic bone.

To further investigate brain injuries resulting from ground-level falls, typically considered low-energy impacts, we analyzed brain CT findings from 72 patients with fall-related zygomatic fractures. Among these, 14 patients (19.4 %) were diagnosed with concomitant brain injury. The occurrence of brain injury was significantly associated with older age but showed no relationship with zygomatic fracture classification or the presence of other concomitant fractures (Table 2). These findings align with previous studies indicating that age-related physiological changes increase susceptibility to intracranial injury following minor trauma.[10,14]

In elderly individuals, progressive brain atrophy leads to an expansion of the subdural space, increasing the brain's mobility within the cranial vault during impact. This anatomical change places greater tension on bridging veins, rendering them more susceptible to rupture.[15] The use of anticoagulant medications further elevates the risk of post-traumatic intracranial hemorrhage, with subdural hematoma (SDH) being the most common manifestation. In our cohort, six patients sustained isolated SDH, one had an epidural hematoma (EDH), one presented with concussion, and four experienced SDH in combination with intracerebral hemorrhage (ICH) or subarachnoid hemorrhage (SAH). Notably, two patients presented with isolated ICH or SAH without a clear correlation to the site of head impact. These cases suggest that the fall may have been secondary to an acute neurological event, such as ICH or SAH, rather than the primary cause of injury, with the zygomatic fracture occurring as a consequence of collapse.

To conclude, patients in this study with zygomatic fractures were generally older than those with mandibular fractures, likely reflecting increased susceptibility to fall-related injuries in the elderly population. Among patients with unilateral zygomatic fractures, more severe fracture patterns were unexpectedly associated with a lower incidence of brain injury, possibly due to the energy-dissipating characteristics of the zygomatic bone. In contrast, bilateral zygomatic fractures were significantly associated with a higher risk of brain injury, likely reflecting the involvement of higher-energy trauma mechanisms. Additionally, older patients with fall-related zygomatic fractures demonstrated a markedly increased risk of concomitant brain injury, highlighting the need for heightened clinical vigilance in this population.

Declaration of competing interests

The authors have no conflicts of interest relevant to this article.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.jds.2025.08.002.

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