Sedlak et al. BMC Emergency Medicine (2025) 25:50
https://doi.org/10.1186/s12873-025-01208-w

BMC Emergency Medicine

RESEARCH Open Access

Acute behavioral changes as a diagnostic factor of intracranial injuries among the elderly population with mild traumatic brain injury - retrospective cross-sectional study

Marian Sedlak[1*], Satria Nur Sya'ban[2], Jozef Dragasek[3], Kornelia Hutnanova[4], Eva Sedlakova[5], Radoslav Morochovic[1] and Rastislav Burda[1]

Abstract

Purpose Mild traumatic brain injury (mTBI) is one of the most common trauma-related diagnoses treated in emergency departments, especially among the geriatric population. Higher age alone is often an indication for a computed tomography (CT) scan, even when, approximately 90% of these scans do not reveal intracranial injuries. Incorporation of new diagnostic parameters into indication schemes for CT scans could improve the efficiency and reduce unnecessary imaging. The primary outcome of this study was to evaluate the association of acute behavioral changes among elderly patients treated for mTBI with the prevalence of intracranial injuries diagnosed by CT scans.

Methods A retrospective cross-sectional study was conducted at Louis Pasteur University Hospital in Košice. All patients aged 65 and older who presented during the period of 12 months with suspected mTBI and underwent CT imaging were included in the study. Electronic health records were used as a data source.

Results A total of 586 patients were included in the study. Acute behavioral changes were observed among 60 (10.2%) patients. Intracranial injury was diagnosed in 35 patients (6.0%). There was a statistically significant association between acute behavioral changes and the presence of intracranial injuries ($p < 0.05$), with those exhibiting behavioral changes having higher odds of injury (OR: 6.51; 3.01–13.7; $p < 0.001$).

Conclusion Elderly patients with mTBI who present with acute behavioral changes are more likely to have intracranial injuries detected by CT scans. Incorporating these symptoms into indication schemes for head CT scans may improve strategies aimed at more effective and judicious use of imaging.

Trial registration Clinical trial number: Not applicable, retrospectively registered.

Keywords Traumatic brain injury, TBI, Mild TBI, Geriatric TBI, Aggression

*Correspondence:
Marian Sedlak
marian.sedlak.md@gmail.com
[1]Department of Trauma Surgery, Faculty of Medicine, Pavol Jozef Safarik University and Louis Pasteur University Hospital, Kosice, Slovakia
[2]School of Public Health, Physiotherapy and Sports Science, University College Dublin, Dublin, Ireland
[3]1st Department of Psychiatry, Pavol Jozef Safarik University and Louis Pasteur University Hospital, Kosice, Slovakia
[4]Department of Pneumology and Phtiseology, Pavol Jozef Safarik University and Louis Pasteur University Hospital, Kosice, Slovakia
[5]Department of Pathological Physiology, Pavol Jozef Safarik University, Kosice, Slovakia

Background

Mild traumatic brain injury (mTBI) is one of the most frequent injury-related diagnoses among the geriatric population, driven by the aging population and a higher incidence of falls among the elderly. It is one of the leading causes of morbidity and mortality among older adults [1–3]. Patients in this cohort are unique due to their physiology, medical conditions, frailty, and polypharmacy. The physiological changes associated with aging, including brain atrophy and increased fragility of cerebral blood vessels, complicate the diagnosis of mTBI in this group [2, 4]. Additionally, psychiatric symptoms such as confusion, agitation, irritability and aggression, which are often linked to qualitative disturbances in consciousness, may further complicate the clinical picture in these patients. These disturbances can serve as important indicators of acute intracranial injuries, especially when classical neurological symptoms like altered Glasgow Coma Scale (GCS) scores are absent [5–7].

Computed tomography (CT) is a standard diagnostic tool for assessing mTBI, primarily due to its effectiveness in detecting acute intracranial injuries, which are the main cause of mortality [8]. Although it is an essential diagnostic tool for identifying serious intracranial injuries, its overuse poses concerns, including cumulative exposure to ionizing radiation, cost implications, and the potential for unnecessary healthcare interventions [9, 10]. In the elderly population with mTBI, almost 90% of CT scans are negative concerning the presence of intracranial injuries [3, 11, 12]. Clinical decision rules, such as the Canadian CT Head Rule or the New Orleans Criteria guide indications for CT scans. However, these guidelines are only partially applicable among older adults, because higher age alone necessitates CT scans in several decision rules [8, 13]. Moreover, elderly patients often present with symptoms and comorbidities that complicate the clinical picture. Given these challenges, there is a growing need to refine further the diagnostic strategies for mTBI among older adults, including the possible utilization of new clinical symptoms, laboratory markers, or the enhancement of clinical criteria that would reduce the reliance on CT scans without compromising the timely detection of clinically significant injuries.

Agitation, irritability, impulsiveness, aggressive, or antisocial behavior are frequently observed after traumatic brain injury [14, 15]. These psychiatric manifestations may occur even in the absence of overt neurological symptoms, making their recognition crucial for timely diagnosis. These disturbances can result from cortical or subcortical injuries and are linked to neurochemical changes, including dysregulation of serotonin and glutamate, which can lead to post-injury psychiatric disorders such as aggression or post-traumatic stress disorder [16]. Several studies assessed their development among patients with a history of TBI, weeks or months after the injury [14, 17]. Some studies have highlighted the role of post-injury irritability and cognitive symptoms as important factors for incomplete recovery in elderly populations [18–20]. However, the timing of their onset, prevalence during the acute phase after injury, or their association with intracranial injuries detected by CT scans in the geriatric population remain unknown.

The primary aim of this study was to assess the presence of acute behavioral changes as a predictive factor of intracranial injuries detected by CT among geriatric patients treated for mTBI in the emergency department.

Methods

Study design

We conducted a single-center, retrospective, descriptive cross-sectional study of geriatric patients aged 65 years and older treated for suspected mild traumatic brain injury in the emergency department of the Louis Pasteur University Hospital in Košice. The study covered a period of 12 months (July 2023 - June 2024). Patients were identified through the hospital's electronic health records system. Records of all patients, who were 65 years and older, and treated in the trauma emergency department were screened for possible primary or concomitant traumatic brain injury. On-duty physicians (trauma surgery, orthopedics, or emergency medicine specialties) conducted and documented patient assessments. Additional data points were extracted from patients' electronic health records. Data analysis was performed in July and August 2024. The primary outcome of this study was to evaluate the association of acute behavioral changes among elderly patients treated at the emergency department due to mTBI with the prevalence of intracranial injuries diagnosed by CT scans. This study has been written according to the "Strengthening The Reporting of OBservational Studies in Epidemiology" (STROBE) guidelines.

Inclusion and exclusion criteria

Electronic records of all patients aged 65 years and older, who were treated in the emergency department for injury-related complaints in the period of July 2023 - June 2024, were screened for suspected or confirmed mild traumatic brain injury up to 48 h before their presentation. The patients had to obtain initial CT scan imaging in the ED. The decision to perform a head CT scan was made by the treating physician. We excluded all patients with severely incomplete or missing data (missing description of patient's behavior, missing multiple secondary outcomes). We also excluded patients with pre-existing cognitive deficits and chronic behavioral changes, who were initially triaged as mTBI patients but whose chronic GCS was not reliably documented and the presenting GCS did not meet mTBI criteria (GCS 13–15).

Methodology

The primary outcome of the study was an assessment of acute behavioral changes as documented by the treating physician and their association with intracranial lesions found on a head CT scan among patients 65 years and older treated in the ED for mild TBI. The type of behavior was assessed according to the description of patients' behavior in the written electronic records and was categorized into one of the following options: no acute behavioral changes; confusion; agitation or irritability or severe restlessness; verbal aggression; and physical aggression. Confusion was defined based on the patient's Glasgow Coma Scale (GCS) verbal response score of 4, or if the medical notes indicated uncertainty on the patient's part regarding their surroundings, actions, or expectations, without any notable impairment in physical presentation or gestures. Agitation, irritability, or severe restlessness were recorded when patients visibly exhibited these behaviors, accompanied by physical changes such as increased movement or altered gestures. These behaviors were considered in conjunction with mental confusion, reflecting a more physically demonstrative response. Verbal aggression was characterized by any documented verbal threats made towards medical staff, which were expressed verbally but not accompanied by physical actions or attempts. Physical aggression was defined as any documented attempt or actual physical attack directed toward medical personnel.

Patients had to obtain their CT scan in the emergency department. All CT scans were evaluated and interpreted immediately after the procedure by a radiologist through a written electronic report. Intracranial lesions were defined as acute epidural, subdural, or subarachnoid hemorrhages, and acute intraparenchymal hemorrhage or brain contusions. In cases of more than one lesion present, a combination of more than two specific findings was reported as a distinct group. Among secondary outcomes, several parameters were collected and analyzed. Basic demographic data contained age, gender, place of injury, cause and mechanism of injury, usage of blood thinners, GCS score, and symptomatology after injury. The type of injury and cutaneous impact location were recorded according to the written description. Any additional injuries and patient outcomes were documented and reported.

Data analysis

Descriptive statistical analysis was performed for all collected variables. Categorical variables are presented as absolute counts and percentages. Continuous variables are presented as means (standard deviations - SD) or medians (Interquartile range - IQR). The differences in central tendencies of categorical variables were analyzed using Chi-square tests and Fisher exact tests.

Two logistic regression models were fitted for the analysis, with the presence of intracranial injury as the dependent variable and the presence of behavioral change as the main independent variable. The first model was adjusted for the covariates: sex and age. The second model was adjusted for sex, age, and alcohol intoxication. Small sample sizes of several behavioral categories were observed and the decision was then taken to collapse specific variables of acute behavioral changes into a binary variable (patients with and without acute behavioral changes). Given the small proportion of missing data (four cases related to alcohol intoxication as a cause of injury), a complete case analysis approach was adopted for the analysis, without applying any data imputation techniques. Both models were evaluated through Akaike Information Criterion (AIC) comparison and likelihood ratio testing. The model quality was evaluated through a pseudoR2 test, and the model's output was interpreted by odds ratio, 95% confidence intervals, and p-values. Data analysis was performed with Rstudio v.2024.09.0 + 375.

Results

The inclusion criteria initially identified 603 patients as candidates for potential enrollment in the study. Following a thorough review of the preliminary data, 17 patients were excluded based on the exclusion criteria. A total of 586 patients were included in the final analysis (Fig. 1).

As the primary outcome, acute behavioral changes were detected in 60 cases (10.2%), no changes were observed among 526 patients (89.8%). Confusion was present in 48 cases (8.2%). Agitation, irritability, and severe restlessness were documented among 5 patients (0.9%), verbal aggression in 4 cases (0.7%), and physical aggression in 3 cases (0.5%). In total, 35 patients (6.0%) were diagnosed with intracranial bleeding. Subdural hemorrhage was the most prevalent finding (13 patients; 2.2%) followed by subarachnoidal hemorrhage (11 patients; 1.9%). Multiple types of intracranial hemorrhages occurred among 8 patients (1.4%). Intraparenchymal hemorrhage or brain contusion was present in 3 cases (0.5%). mTBI was recorded as an isolated injury in 359 cases (61.8%). Acute behavioral changes among the elderly population with mild traumatic brain injury were associated with the presence of intracranial injuries detected by CT scans ($p < 0.05$). Among secondary outcomes, the median age of the study population was 79.00 years (IQR 73.00–85.00), from whom 232 (39.6%) were male. Shapiro-Wilk and Kolmogorov-Smirnov tests revealed a non-normal age distribution within the study population. Most accidents happened at home (241 patients; 41.4%) or outside (214 patients; 36.5%). The most frequent mechanism of injury was ground-level fall or injury during ground-level fall (468 patients; 79.9%). The cause of injury was mostly attributed to mechanic reasons (342 patients; 58.4%),

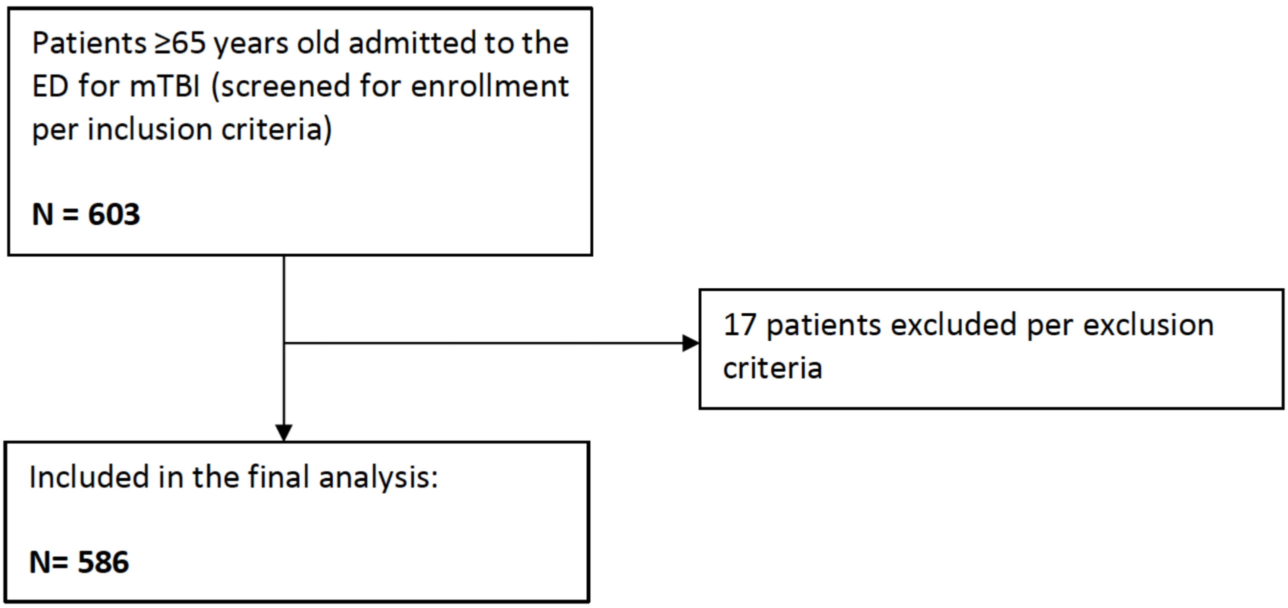

Fig. 1 Flow diagram

followed by alcohol intoxication (89 patients; 15.2%) (Tables 1 and 2).

On presentation at the emergency department, 499 patients (85.2%) had a GCS score of 15. The majority of patients did not report any subjective symptoms after injury (338 patients; 57.7%). The most prevalent signs and symptoms after injury among the rest of patients were amnesia (124 patients; 21.2%), followed by diffuse headache (32 patients; 5.5%), and a combination of more than 2 complaints (31 patients; 5.3%). Unequal pupils were recorded in one case (0.2%). The usage of blood thinners was recorded among 273 patients (46.6%). Antiplatelet treatment was the most prevalent option (159 patients; 27.1%), followed by DOACs (83 patients; 14.2%) and LMWH (17 patients; 2.9%). No visible signs of injury were observed in 115 cases (19.6%), abrasion / wound not requiring suture was recorded in 157 patients (26.8%), haematoma in 139 patients (23.7%), and wound requiring suture in 175 cases (29.9%). Cutaneous impact location in a facial location was recorded in 89 cases (15.2%), in a frontal location in 163 cases (27.8%) and in scalp location in 219 cases (37.4%). No visible cutaneous impact location was recorded among 115 patients (19.6%). The most prevalent additional finding was peripheral wound or contusion (98 patients; 16.7%), followed by complicated facial bone fracture(s) (39 patients; 6.7%), upper limb fractures (33 patients; 5.6%), lower limb fractures (15 patients; 2.6%), and skull fractures (14 patients; 2.4%). Outpatient treatment was the preferred management for 439 patients (74.9%), 142 patients (24.2%) were admitted to the hospital for any reason. Additionally, neurosurgical treatment during hospital stay was required in 4 cases (0.7%), and one patient died in the emergency department (0.2%), the cause of death was not the traumatic brain injury (Tables 1 and 2). The results of additional analyses are presented in Table 3.

Two logistic regression models were fitted for the analysis, with the presence of intracranial injury as the dependent variable and the presence of behavioral change as the main independent variable. The first model was adjusted for the covariates: sex and age. The second model was adjusted for sex, age, and alcohol intoxication (to isolate the effect of alcohol intoxication). Small sample sizes of several behavioral categories were observed and the decision was then taken to collapse specific variables of acute behavioral changes into a binary variable (patients with and without acute behavioral changes). Alcohol intoxication was included in the second model, recoded from five categories into a binary one, specifically focusing on whether alcohol intoxication was associated with intracranial injuries, based on evidence in the literature (Table 4).

In the model without alcohol intoxication, adjusted for sex and age, patients with behavioral change upon admission have 6.98 times higher odds of having CT-confirmed intracranial injury compared to those without (OR 6.98; 95% CI: 3.26–14.6; $p < 0.00$). In the model with alcohol intoxication (other variables held constant) OR was computed with a slightly lower variance (OR: 6.51; 95% CI:3.01–13.7; $p < 0.001$), the effect has remained significant. Intoxication with alcohol was not found to be significantly correlated with the odds of having intracranial injury in this model (OR: 1.88; 95% CI: 0.76–4.46; $p = 0.2$) (Table 5). Multiple testing was done to evaluate the quality of the models, the results of the analyses are in the Table 5.

Table 1 Summary of patient demographics and characteristics ($N = 586$)

Variable	N	%
Age (yrs)		
Mean (SD)	78.9	7.8
65–72	146	24.9
72–79	156	26.6
79–85	156	26.6
≥ 85	128	21.8
Gender		
Male	232	39.6
Female	354	60.4
Place of Injury		
Retirement Home / Senior Facility	70	11.9
Another Healthcare Facility	14	2.4
Home	241	41.1
Outside	214	36.5
Missing	47	8.0
Mechanisms of Injury		
Ground-level fall or injury during ground-level fall	468	79.9
Found on the ground, mechanism not clear	44	7.5
Fall from a height (stairs etc.)	38	6.5
Traffic accident	19	1.7
Interpersonal violence	10	1.4
Missing	8	1.4
Cause of Injury		
Mechanic	342	58.4
Transient loss of consciousness (TLOC)	70	11.9
Vertigo / seizures	35	6.0
Alcohol intoxication	89	15.2
Unclear	46	7.8
Missing	4	0.7
Usage of blood thinners		
None	183	31.2
DOAC	83	14.2
Warfarin	11	1.9
Antiplatelet	159	27.1
LMWH	17	2.9
Antiplatelet + DOAC	2	0.3
Antiplatelet + LMWH	1	0.2
Missing	130	22.2
Emergency department management		
Outpatient treatment	439	74.9
Admitted to hospital due to any reason	142	24.2
Neurosurgical treatment during hospital stay	4	0.7
Death in the emergency department	1	0.2

Discussion

This study aimed to explore the relationship between acute behavioral changes among elderly patients with mild TBI recorded during emergency department management and the presence of intracranial injuries detected by CT scans. The prevalence of intracranial injuries in this cohort was consistent with similar studies (35 patients; 6.0%) [3, 11, 12, 21]. The high prevalence of subdural hemorrhages (2.2%) and subarachnoid hemorrhages (1.9%) is consistent with previous studies that highlight these types of injuries as common findings in elderly patients with mTBI [3, 11]. The prevalence of combined intracranial injuries with two or more types of intracranial bleeding (8 patients; 1.4%) is relatively high as well. Combined injuries are sometimes not reported and the “less severe” type of bleeding is collapsed into another category, which is perceived as “more severe”, which can alter the overall data [2]. Epidemiology and outcomes of such combined injuries are therefore not assessed thoroughly. The results indicate that acute behavioral changes are relatively rare, with 89.8% of patients showing no such symptoms. Confusion was the most common behavioral change, occurring in 8.2% of cases, followed by agitation, verbal aggression, and physical aggression in fewer than 1% of patients. Acute behavioral changes were shown to be significantly associated with the odds of intracranial hemorrhage in both logistic regression models (adjusted for sex, and age as confounding factors) (OR: 6.98; 95% CI: 3.26–14.6; $p < 0.001$; respectively with alcohol intoxication as an additional confounding factor: OR: 6.51; 95% CI: 3.01–13.7; $p < 0.001$).

Evaluation of elderly patients with mTBI is challenging due to their unique physiology and specific considerations, including usage of medications, or the impact of TBI itself. Several studies have suggested that GCS score may differ in its interpretation when applied to elderly population (over 65 years old) compared to younger patients. This difference can limit its reliability in accurately reflecting the severity of TBI, particularly during the early stages of patient assessment [5–7]. Acute behavioral changes may further complicate thorough assessment of patients’ neurological status, level of cognitive functions and overall their impairment of consciousness. Even in the absence of more overt “classical” symptoms of intracranial injuries, a thorough examination of patients’ psychological status and behavioral alterations may serve as an important indicator in this population. Several theories have been proposed to explain the development of long-term psychiatric problems following mTBI, including violent behavior or post-traumatic stress disorder, including disruptions in neuromodulators’ intake [14, 16]. Their specific dynamics, onset of presentation and their early association with intracranial injuries detected by CT scans are unknown. In this context, confusion, agitation, or aggression may not only reflect post-traumatic disorientation but also indicate more severe intracranial injuries requiring prompt intervention. Moreover, these symptoms might reveal an increased psychiatric vulnerability in elderly patients, where underlying cognitive decline or pre-existing mental health conditions could exacerbate the behavioral impact of mTBI [14].

Table 2 Summary of patient clinical findings ($N=586$)

Variable	*N*	%
GCS Score		
13	10	1.7
14	77	13.1
15	499	85.2
Pupilary examination - new changes		
Equal	585	99.8
Unequal	1	0.2
Clinical symptoms after injury		
None	338	57.7
Loss of consciousness	19	3.2
Vomiting (≥ 2 episodes)	3	0.5
Amnesia	124	21.2
New focal neurological deficit	9	1.5
Combination of ≥ 2 symptoms	31	5.3
Signs of skull fracture	4	0.7
Diffuse headache	32	5.5
Undocumented / unable to evaluate	26	4.4
New behavioral changes		
None	526	89.8
Confusion	48	8.2
Agitation, irritability, severe restlessness	5	0.9
Verbal aggression	4	0.7
Physical aggression	3	0.5
Type of injury		
No signs of injury	115	19.6
Abrasion / wound not requiring suture	157	26.8
Haematoma	139	23.7
Wound requiring suture	175	29.9
Cutaneous Impact Location		
No visible CIL	115	19.6
Facial	89	15.2
Frontal	163	27.8
Scalp	219	37.4
Presence of Intracranial Injury		
No	551	94.0
Yes	35	6.0
Injury Type Based on CT Findings		
Normal	548	93.5
Subdural bleeding	13	2.2
Subarachnoideal bleeding	11	1.9
Intraparenchymal bleeding / contusion	3	0.5
Combination of ≥ 2 type of bleeding	8	1.4
Other findings (tumor, stroke, chronic lesions, etc.)	3	0.5
Additional Injuries		
None	359	61.3
Wound or contusion anywhere else	98	16.7
Complicated facila bone fracture(s)	39	6.7
Cervical vertebrae fracture	6	1.0
Lower limb fracture	15	2.6
Upper limb fracture	33	5.6
Pelvic fracture / thoracic or lumbal vertebral fracture	11	1.9
Rib fracture(s)	6	1.0
Skull fracture	14	2.4
Missing	5	0.9

One notable aspect of this study is the relatively low rate of intracranial hemorrhages compared to the overall number of patients undergoing CT scans, even among patients using blood thinners. This supports the growing concern about the overuse of CT imaging in elderly patients with mTBI, where nearly 90% of scans do not reveal any significant intracranial pathology [3, 11, 12, 22]. Current most widely used clinical decision rules such as the Canadian CT Head Rule (CCHR) and the New Orleans Criteria have limited applicability in older adults since age alone often necessitates a CT scan, without any other factors [8, 13]. The gaps in knowledge regarding the management of elderly patients further include the identification of screening tools in elderly patients with significant confounders, including criteria for brain imaging, the role of biomarkers, or specific CT/MRI rules (or criteria for patients presenting > 24 h. from injury) [23].

In addition to the primary outcomes, the secondary outcomes highlight several risk factors that may contribute to the increased vulnerability of elderly patients to mTBI. Falls were the most common mechanism of injury, which aligns with previous literature suggesting that age-related frailty and balance issues resulting in frequent falls are key contributors to mTBI in this population [2, 4]. Cutaneous impact location was associated with the presence of intracranial injuries, in particular among patients who had an injury in the scalp area (54% of patients with intracranial injuries had an impact in this location). This finding is consistent with several studies documenting this association [22, 24]. The use of blood thinners, particularly antiplatelet agents and direct oral anticoagulants (DOACs), was also prevalent in this cohort, but with no association with the presence of intracranial injuries. Usage of blood thinners as a risk factor for intracranial injuries is a frequently debated question with several studies focusing on this problem. The results are often uncertain, with several studies showing slightly higher risk among patients with dual antiplatelet therapy or warfarin, in contrast with DOACs, which seem to have better safety profiles [25–27].

Limitations

The study had several limitations. The retrospective nature of this study posed numerous challenges. The reliance on electronic health records for behavioral assessments introduces potential bias, as these symptoms may have been underreported or inconsistently documented. While the sample size is significant, multiple categories within collected variables made certain statistical analyses less accurate. Increasing the number of observations in future studies may alleviate this and plausibly provide a more accurate representation of the effect size of the exposure variables towards the outcome. Behavioral and psychiatric symptoms, such as confusion, agitation, or

Table 3 Factors associated with intracranial injuries

No	Independent Variable	Chi-square				Fisher exact test	
		N	X2	df	*p*-value	F	*p*-value
1	Sex	585	2.181	1	0.14		
2	Age (Quartile)	586	0.281	3	0.96		
3	Place of Injury	586	4.511	3	0.21	4.904	0.157
4	Mechanisms of Injury	578	16.555	4	0.002	11.2	0.014
5	Cause of Injury	582	8.974	4	0.062	7.437	0.093
6	Usage of blood thinners	456	4.787	6	0.571	5.532	0.468
7	GCS Score	586	8.237	2	0.016	7.822	0.016
8	Pupilary examination - new changes	586	0.064	1	0.801		1
9	Clinical symptoms after injury	586	96.702	8	< 0.001	57.197	< 0.001
10	New behavioral changes	586	94.041	4	< 0.001	43.69	< 0.001
11	Type of injury	586	13.262	3	0.004		
12	Cutaneous impact location	586	9.453	3	0.024		
13	Additional injuries	581	194.48	8	< 0.001	74.06	< 0.001

Table 4 Clinical findings stratified according to the presence of intracranial injury for the purpose of logistical regression models (*N* = 582)

Variable	Overall (*N*;%)	Intracranial injury		*p*-value
		No (*N* = 547; %)	Yes (*N* = 35; %)	
Sex				0.200
Male	352 (60%)	335 (61%)	17 (49%)	
Female	230 (40%)	212 (39%)	18 (51%)	
Age (IQR)	79 (73, 85)	79 (73, 85)	79 (71, 85)	> 0.9
Place of Injury				0.141
Retirement Home / Senior Facility	70 (13%)	66 (13%)	4 (12%)	
Another Healthcare Facility	14 (2.6%)	12 (2.4%)	2 (6.1%)	
Home	240 (45%)	230 (46%)	10 (30%)	
Outside	213 (40%)	196 (39%)	17 (52%)	
Missing	45	43	2	
Mechanisms of Injury				0.014
Ground-level fall or injury during ground-level fall	465 (81%)	441 (82%)	24 (69%)	
Found on the ground, mechanism not clear	43 (7.5%)	41 (7.6%)	2 (5.7%)	
Fall from a height (stairs etc.)	38 (6.6%)	30 (5.6%)	8 (23%)	
Traffic accident	19 (3.3%)	18 (3.3%)	1 (2.9%)	
Interpersonal violence	9 (1.6%)	9 (1.7%)	0 (0%)	
Missing	8	8.0	0.0	
Cause of Injury				0.101
Mechanic	342 (59%)	325 (59%)	17 (49%)	
Transient loss of consciousness (TLOC)	70 (12%)	65 (12%)	5 (14%)	
Vertigo / seizures	35 (6.0%)	34 (6.2%)	1 (2.9%)	
Alcohol intoxication	89 (15%)	78 (14%)	11 (31%)	
Unclear	46 (7.9%)	45 (8.2%)	1 (2.9%)	
Missing	4	4	0	
Usage of blood thinners				0.512
None	183 (40%)	165 (39%)	18 (55%)	
DOAC	83 (18%)	78 (19%)	5 (15%)	
Warfarin	11 (2.4%)	11 (2.6%)	0 (0%)	
Antiplatelet	157 (35%)	149 (35%)	8 (24%)	
LMWH	17 (3.7%)	15 (3.6%)	2 (6.1%)	
Antiplatelet + DOAC	2 (0.4%)	2 (0.5%)	0 (0%)	
Antiplatelet + LMWH	1 (0.2%)	1 (0.2%)	0 (0%)	
Missing	128	126	2	

Table 4 (continued)

Variable	Overall (N;%)	Intracranial injury		p-value
		No (N = 547; %)	Yes (N = 35; %)	
GCS Score				0.023
13	10 (1.7%)	9 (1.6%)	1 (2.9%)	
14	77 (13%)	67 (12%)	10 (29%)	
15	495 (85%)	471 (86%)	24 (69%)	
Pupillary examination - new changes				> 0.900
Equal	581 (99.8%)	546 (99.8%)	35 (100%)	
Unequal	1 (0.2%)	1 (0.2%)	0 (0%)	
Clinical symptoms after injury				< 0.001
None	338 (58%)	330 (60%)	8 (23%)	
Loss of consciousness	17 (2.9%)	15 (2.7%)	2 (5.7%)	
Vomiting (≥ 2 episodes)	3 (0.5%)	2 (0.4%)	1 (2.9%)	
Amnesia	122 (21%)	117 (21%)	5 (14%)	
New focal neurological deficit	9 (1.5%)	5 (0.9%)	4 (11%)	
Combination of ≥ 2 symptoms	31 (5.3%)	19 (3.5%)	12 (34%)	
Signs of skull fracture	4 (0.7%)	4 (0.7%)	0 (0%)	
Diffuse headache	32 (5.5%)	30 (5.5%)	2 (5.7%)	
Undocumented / unable to evaluate	26 (4.5%)	25 (4.6%)	1 (2.9%)	
New behavioral changes				< 0.001
None	522 (90%)	501 (92%)	21 (60%)	
Confusion	48 (8.2%)	42 (7.7%)	6 (17%)	
Agitation, irritability, severe restlessness	5 (0.9%)	1 (0.2%)	4 (11%)	
Verbal aggression	4 (0.7%)	1 (0.2%)	3 (8.6%)	
Physical aggression	3 (0.5%)	2 (0.4%)	1 (2.9%)	
Type of injury				0.011
No signs of injury	113 (19%)	110 (20%)	3 (8.6%)	
Abrasion / wound not requiring suture	157 (27%)	150 (27%)	7 (20%)	
Haematoma	138 (24%)	121 (22%)	17 (49%)	
Wound requiring suture	174 (30%)	166 (30%)	8 (23%)	
Cutaneous Impact Location				0.027
No visible CIL	113 (19%)	110 (20%)	3 (8.6%)	
Facial	89 (15%)	88 (16%)	1 (2.9%)	
Frontal	162 (28%)	150 (27%)	12 (34%)	
Scalp	218 (37%)	199 (36%)	19 (54%)	
Additional Injuries				< 0.001
None	357 (62%)	345 (64%)	12 (34%)	
Wound or contusion anywhere else	97 (17%)	92 (17%)	5 (14%)	
Complicated facila bone fracture(s)	39 (6.7%)	37 (6.8%)	2 (5.7%)	
Cervical vertebrae fracture	6 (1.0%)	5 (0.9%)	1 (2.9%)	
Lower limb fracture	15 (2.6%)	15 (2.8%)	0 (0%)	
Upper limb fracture	33 (5.7%)	32 (5.9%)	1 (2.9%)	
Pelvic fracture / thoracic or lumbal vertebral fracture	11 (1.9%)	10 (1.8%)	1 (2.9%)	
Rib fracture(s)	6 (1.0%)	6 (1.1%)	0 (0%)	
Skull fracture	14 (2.4%)	1 (0.2%)	13 (37%)	
Missing	4	4	0	

aggression, are often subject to underreporting, particularly in the elderly who may be unable to articulate their symptoms effectively. Additionally, the presence of cognitive impairments or pre-existing psychiatric disorders may obscure the true nature of the behavioral changes observed during ED visits, requiring more comprehensive psychiatric assessments in future studies. The same applies to potential confounding factors of acute behavioral changes, which are often underreported or not recognized during the ED visit, such as chronic impairment of cognitive functions, acute intoxications, or influence of other medical and social factors. Future prospective studies with standardized behavioral assessments are necessary to validate these findings and further clarify the role

Table 5 Logistic regression models

Model 1: without alcohol intoxication				Model 2: with alcohol intoxication			
Characteristic	**OR**	**95% CI**	***p*-value**	**Characteristic**	**OR**	**95% CI**	***p*-value**
Sex				**Sex**			
Male	---	---		Male	---	---	
Female	1.51	0.73, 3.09	0.3	Female	1.27	0.59, 2.73	0.5
Age	0.98	0.94, 1.03	0.5	**Age**	0.99	0.95, 1.04	0.7
Acute behavioral changes				**Acute behavioral changes**			
No behavioral change	---	---		No behavioral change	---	---	
Behavioral Change Present	6.98	3.26, 14.6	< 0.001	Behavioral Change Present	6.51	3.01, 13.7	< 0.001
				Mechanism of injury			
				Non-alcohol related			
				Alcohol intoxication	1.88	0.76, 4.46	0.2
Pseudo R-squared for model 1:				**Pseudo R-squared for model 2**:			
Log-likelihood	-119.665			Log-likelihood	-118.717		
Null Log-likelihood	-132.315			Null Log-likelihood	-132.315		
G2 (Likelihood Ratio Test Statistic)	25.299			G2 (Likelihood Ratio Test Statistic)	27.195		
McFadden's R-squared	0.096			McFadden's R-squared	0.103		
ML R-squared	0.043			ML R-squared	0.045		
Cox & Snell's R-squared	0.116			Cox & Snell's R-squared	0.125		

of behavioral symptoms in predicting intracranial injuries in geriatric patients with mTBI.

Generalisability

The findings of this study contribute important insights into the relationship between acute behavioral changes and intracranial injuries in elderly patients with mTBI in the emergency department setting. While the study's sample size and specific population provide relevant data, its generalisability may be limited to settings with similar demographics, healthcare resources, and clinical practices. The relatively low rate of intracranial hemorrhage observed, even among patients using blood thinners, might not be directly applicable to populations with different anticoagulant usage patterns or access to imaging technology. Alcohol intoxication as a cause of injury and a confounder of patients' presentation is another setting-specific factor, which may be limited to this cohort. Additionally, the retrospective study design, relying on electronic health records, may limit the consistent assessment of behavioral symptoms, possibly affecting the transferability of results to contexts where behavioral assessments follow standardized protocols.

Interpretation and conclusions

This study contributes to a deeper understanding of the role that acute behavioral symptoms, such as confusion, agitation, and aggression, play in the diagnostic process of traumatic brain injury in the geriatric population. The findings suggest that incorporating behavioral changes into clinical indication protocols for CT scans could lead to more effective and targeted use of CT imaging. Beyond their diagnostic value for intracranial injuries, these behavioral symptoms may also signal underlying psychiatric vulnerabilities in elderly patients, which, if unaddressed, could result in long-term psychiatric complications such as post-traumatic stress disorder, aggression, or cognitive decline. Future prospective studies are needed to validate these results and explore whether refined diagnostic criteria including psychiatric assessments, can optimize patient outcomes while minimizing unnecessary radiation exposure and resource use.

Abbreviations

95% CI	95% confidence interval
AIC	Akaike Information Criterion
CT	Computed tomography
DOACs	Direct oral anticoagulants
ED	Emergency department
GCS	Glasgow Coma Scale
IQR	Interquartile range
LMWH	Low molecular weight heparin
mTBI	Mild traumatic brain injury
OR	Odds ratio
SD	Standard deviation
mTBI	Mild traumatic brain injury
TBI	Traumatic brain injury

Author contributions

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by Marian Sedlak, Satria Nur Sya'ban, Rastislav Burda and Radoslav Morochovic. The first original draft of the manuscript was written by Marian Sedlak, Jozef Dragasek, Kornelia Hutnanova and Eva Sedlakova. All authors commented on previous versions of the manuscript. All authors read and approved the final manuscript.

Funding

The authors did not receive support from any organization for the submitted work.

Data availability

The dataset collected during the study is available from the corresponding author on reasonable request.

Declarations

Ethical approval
The study was approved by the Ethics Committee of Louis Pasteur University Hospital in Kosice, Slovakia (code of approval: 2024/EK/06058). In view of the retrospective nature of the study and all the procedures being performed were part of the routine care. The study was performed in accordance with the ethical standards as laid down in the 1964 Declaration of Helsinki and its later amendments or comparable ethical standards.

Consent for publication
Not applicable.

Competing interests
The authors declare no competing interests.

Received: 20 November 2024 / Accepted: 21 March 2025
Published online: 29 March 2025

References
1. Fakhry SM, et al. The burden of geriatric traumatic brain injury on trauma systems: Analysis of 348,800 medicare inpatient claims. J Am Geriatr Soc. 2023;71(2):516–27. https://doi.org/10.1111/jgs.18114.
2. Hawley C, et al. Traumatic brain injuries in older adults—6 years of data for one UK trauma centre: Retrospective analysis of prospectively collected data. Emerg Med J. 2017;34(8):509–16. https://doi.org/10.1136/emermed-2016-206506.
3. Mower WR et al. Blunt head injury in the elderly: Analysis of the NEXUS II injury cohort. Annals of emergency medicine 83.5. 2024: 457–66. https://doi.org/10.1016/j.annemergmed.2024.01.003
4. Hwang H-F et al. Risk factors for traumatic brain injuries during falls in older persons. The Journal of head trauma rehabilitation 30.6. 2015:E9-E17. https://doi.org/10.1097/HTR.0000000000000093
5. Kehoe A, et al. Older patients with traumatic brain injury present with a higher GCS score than younger patients for a given severity of injury. Emerg Med J. 2016;33(6):381–5. https://doi.org/10.1136/emermed-2015-205180.
6. Mercier E, Mitra B, Peter A. Cameron. Challenges in assessment of the mild traumatic brain injured geriatric patient. Injury 47.5. 2016:985–7. https://doi.org/10.1016/j.injury.2016.04.001
7. Salottolo K et al. The effect of age on Glasgow coma scale score in patients with traumatic brain injury. JAMA surgery 149.7. 2014:727–34. https://doi.org/10.1001/jamasurg.2014.13
8. Stiell IG et al. A prospective cluster-randomized trial to implement the Canadian CT head rule in emergency departments. Cmaj 182.14. 2010:1527–32. https://doi.org/10.1503/cmaj.091974
9. Klang E, et al. Overuse of head CT examinations for the investigation of minor head trauma: Analysis of contributing factors. J Am Coll Radiol. 2017;14(2):171–6. https://doi.org/10.1016/j.jacr.2016.08.032.
10. Rezaee M, et al. Overutilization of head computed tomography in cases of mild traumatic brain injury: A systematic review and meta-analysis. Emerg Radiol. 2024;1–15. https://doi.org/10.1007/s10140-024-02247-9.
11. Kerstin deW, et al. Incidence of intracranial bleeding in seniors presenting to the emergency department after a fall: A systematic review. Injury. 2020;51(2):157–63. https://doi.org/10.1016/j.injury.2019.12.036.
12. Dubucs X, et al. Head injuries in prehospital and emergency department settings: A prospective multicenter cross-sectional study in France. BMC Emerg Med. 2024;24:207. https://doi.org/10.1186/s12873-024-01124-5.
13. Smits M et al. External validation of the Canadian CT Head Rule and the New Orleans Criteria for CT scanning in patients with minor head injury. Jama 294.12. 2005:1519–1525. https://doi.org/10.1001/jama.294.12.1519
14. Miles SR, et al. Evolution of irritability, anger, and aggression after traumatic brain injury: Identifying and predicting subgroups. J Neurotrauma. 2021;38(13):1827–33. https://doi.org/10.1089/neu.2020.7451.
15. Maresca G, et al. Traumatic brain injury and related antisocial behavioral outcomes: A systematic review. Med 59. 2023;8:1377. https://doi.org/10.3390/medicina59081377.
16. Gruenbaum BF, et al. The relationship between post-traumatic stress disorder due to brain injury and glutamate intake: A systematic review. Nutrients 16. 2024;6901. https://doi.org/10.3390/nu16060901.
17. Reznik ME et al. Agitation after subarachnoid hemorrhage: A frequent omen of hospital complications associated with worse outcomes. Neurocritical care 26. 2017:428–35. https://doi.org/10.1007/s12028-016-0331-1
18. Hume CH, Bradley J, Wright, Glynda J. Kinsella. Systematic review and meta-analysis of outcome after mild traumatic brain injury in older people. J Int Neuropsychol Soc. 2022;28(7):736–55. https://doi.org/10.1017/S1355617721000795.
19. Kristman VL et al. Prognostic markers for poor recovery after mild traumatic brain injury in older adults: A pilot cohort study. The Journal of head trauma rehabilitation 31.6. 2016:E33-E43. https://doi.org/10.1097/HTR.0000000000000226
20. Bittencourt M, et al. Self-reported complaints as prognostic markers for outcome after mild traumatic brain injury in elderly: A machine learning approach. Front Neurol. 2021;12:751539. https://doi.org/10.3389/fneur.2021.751539.
21. Gardner RC, et al. Geriatric traumatic brain injury: Epidemiology, outcomes, knowledge gaps, and future directions. J Neurotrauma. 2018;35(7):889–906. https://doi.org/10.1089/neu.2017.5371.
22. Sedlák Marián, et al. Cutaneous impact location predicts intracranial injury among the elderly population with traumatic brain injury. Open Access Emerg Med. 2023;265–75. https://doi.org/10.2147/OAEM.S422785.
23. Backus BE, et al. Consensus paper on the assessment of adult patients with traumatic brain injury with Glasgow coma scale 13–15 at the emergency department: A multidisciplinary overview. Eur J Emerg Med. 2024;10–1097. https://doi.org/10.1097/MEJ.0000000000001140.
24. Dubucs X et al. Validation of the cutaneous impact location to predict intracranial lesion among elderly admitted to the emergency department after a ground-level fall. Injury 54.5. 2023:1306–13. https://doi.org/10.1016/j.injury.2023.02.023
25. Santing JAL, et al. Mild traumatic brain injury in elderly patients receiving direct oral anticoagulants: A systematic review and meta-analysis. J Neurotrauma. 2022;39:7–8. https://doi.org/10.1089/neu.2021.0435.
26. Mathieu François, et al. Impact of antithrombotic agents on radiological lesion progression in acute traumatic brain injury: A CENTER-TBI propensity-matched cohort analysis. J Neurotrauma. 2020;37(19):2069–80. https://doi.org/10.1089/neu.2019.6911.
27. Hecht JP, et al. Effect of preinjury oral anticoagulants on outcomes following traumatic brain injury from falls in older adults. Pharmacotherapy: J Hum Pharmacol Drug Therapy. 2020;40(7):604–13. https://doi.org/10.1002/phar.2435.

Publisher's note