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Early neurological deterioration in older adults with traumatic brain injury

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ABSTRACT

Introduction: Traumatic brain injuries (TBIs) and resulting fatalities among older adults increased considerably in recent years. Neurological deterioration often goes unrecognized at the injury scene and patients arrive at emergency departments with near-normal Glasgow Coma Scale (GCS) scores. This study examined the proportion of older adults experiencing early neurological deterioration (prehospital to emergency department), associated factors, and association of the magnitude of neurological deterioration with TBI severity.
Methods: This secondary analysis of National Trauma Data Bank Research Datasets included patients who were age $\geqslant$65, sustained a TBI, and transported from the injury scene to an emergency department. Data analysis included chi-square analysis, *t*-tests, and logistic regression. Long-term anticoagulant/antiplatelet therapy was not associated with deterioration.
Results: Of the sample of 91,886 patients, 13,913 (15.1%) experienced early neurological deterioration. Adjusting for covariates, age, gender, head AIS_{max} injury severity, and probability of death were associated with early deterioration. Patients with severe and critical head injuries had the highest odds of early neurological deterioration (OR = 1.41 [CI = 1.22–1.63] and OR = 1.98 [CI = 1.63–2.40], $p < 0.001$).
Discussion/conclusions: Prehospital providers, nurses, physicians, and other providers have opportunities to optimize outcomes from older adult TBI through early recognition of neurological deterioration, rapid transport to facilities for definitive treatment, and targeted rehabilitation.

1. Introduction

The incidence of traumatic brain injury (TBI) hospitalizations and deaths among older adults has spiked in recent years [9]. Although many of these brain injuries are life threatening, the likelihood of treatment at a trauma center hospital declines with age [31]. Injury severity is often unrecognized at the scene and patients arrive at emergency departments (EDs) with near normal Glasgow Coma Scale (GCS) scores [7,24,35]. Falls are the primary mechanism of injury among older adults who sustain a TBI [10]. Many falls are low energy slip and trip falls, which often present as innocuous injuries to laypersons and emergency responders. Unfortunately, early presentation can be deceiving, with many low energy falls resulting in brain hemorrhage and even death.

Brain hemorrhage and swelling increase intracranial pressure, risking severe disability and death [4]. Recognizing prehospital neurological deterioration identifies opportunities for early intervention to mitigate damage [6,27], including transport of the injured person to a trauma center for timely, definitive treatment. Many prehospital trauma triage guidelines use the Glasgow Coma Scale (GCS) to guide intervention, determining the need for trauma center transport. Prehospital trauma triage guidelines in the United States indicate trauma center transport for patients with a GCS score of $\leqslant$13 [36]. However, scientific evidence of the effectiveness of this GCS score cut-point in screening for TBI during the prehospital period in an older adult population remains controversial [8,36]. What is clear, though, is that a deteriorating GCS score warrants further evaluation and transport to a trauma center.

A noted gap in the literature is the paucity of evidence comparing *older adults'* prehospital and ED GCS scores to identify neurological deterioration and its predictors. This gap is important because previous evidence suggests that older adults, compared to younger adults, with moderate and severe head injuries, are more likely to present to the ED with normal or near-normal GCS scores, thus masking the severity of their TBIs [24]. Furthermore,

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older adults at each injury severity stratum have a higher risk of dying [35]. Therefore, the ability to identify older adults at risk for early neurological deterioration provides opportunities for early intervention and subsequent improvement of outcomes. Our study aims, which addressed this gap, were to determine the proportion of older adults with TBIs whose GCS score deteriorated from prehospital to ED assessment, factors associated with a decrease in GCS score, and the association of the magnitude of GCS score deterioration with the anatomic severity of the brain injury.

2. Background/literature

In an effort to identify brain-injured older patients at risk for neurological deterioration, we reviewed studies of injured adults that evaluated prehospital and ED GCS scores [3,5,12,13,14,15,25,27]. These studies focused on two patient populations: patients with TBIs and patients with unspecified injuries. Findings were similar for both populations, including no significant differences in prehospital and ED GCS scores [13,14], neurological deterioration among nonsurvivors [12], and a mix of improved GCS scores [5,15] and deteriorated GCS scores [27]. The proportion of patients who deteriorated was greatest for patients with ED GCS scores in the severe range [25,27], including those whose GCS deterioration was more than two points [27]. Among patients whose GCS scores improved from prehospital to ED, the GCS median score improvement was two points, from a prehospital GCS = 12 to an ED GCS = 14 [5,15]. Although these studies included adults of all ages, the mean ages ranged from 40 to 50 years and none included a sub-group analysis of older adults.

Additional evidence suggests that early GCS scores underestimate the presence and severity of TBIs among older adults who presented with near-normal GCS scores in the ED [24,35,37]. In a comparison of head Abbreviated Injury Scale (AIS) 3–5 scores (serious, severe, or critical injury) among undertriaged and correctly triaged older patients, the median ED GCS score for both groups was 14, suggesting a mild head injury, when in fact, the actual AIS severity was much greater [37]. In another study examining ED GCS severity among older adults, 90.1% of patients with head AIS 3 scores (serious injury), 83% of those with head AIS 4 scores (severe injury), and 56.3% with head AIS 5 (critical injury) scores presented with GCS scores of 13–15 [35]. Similarly, other investigators reported higher GCS median scores among older adults compared to younger adults for each head AIS category [24].

3. Methods

This study is a secondary analysis of de-identified data from the National Trauma Data Bank (NTDB) Research Dataset (RDS) from admission years of 2009–2012 [1]. The NTDB is a voluntary registry of trauma admissions from participating trauma centers in the United States. This registry includes data on the trauma admission; events during the pre-hospital, admission, and discharge phases; outcomes; and variables describing the hospital.

The university Institutional Review Board granted an exemption for this study according to 45 CFR 46.101(b), category 4, use of existing data.

3.1. Sample

Participants included in our study were age 65 years and older, had a Barell Injury Diagnosis Matrix of TBI type 1, 2, or 3 [30], and were transported directly from the injury scene to the ED. Interfacility transfers were excluded.

3.2. Measures and covariates

TBI was defined by the Barell Injury Diagnosis Matrix ICD-9-CM codes for TBI [30]. These codes include 800, 801, 803, 804.03-0.05, 804.1, 804.2, 804.3-0.4, 804.53-0.5, 804.6-0.9, 850.2-0.4, 851–854, 950.1-0.3. These diagnosis codes include open and closed skull fractures, intracranial injury with and without loss of consciousness, cerebral contusions and lacerations, and intracranial bleeding.

The head AIS score quantified TBI severity in this study. The anatomically-derived AIS score is based on diagnostic and autopsy findings [16]. AIS score severity is classified as 1 = minor, 2 = moderate, 3 = serious, 4 = severe, 5 = critical, 6 = unsurvivable [35]. The AIS scoring system is the international gold standard for classifying injury severity [16] and has been validated in several studies [23,26]. The head AIS maximum (AIS_{max}) score refers to the highest head AIS score recorded for the patient.

Early neurological deterioration was defined as a decrease in the GCS score from the prehospital assessment to the ED assessment. The GCS measures level of consciousness, including arousal, awareness, and responsiveness [39]. Scoring ranges from 3 (no response) to 15 (fully responsive) on the GCS_{total}. Three subscales assess eye opening (1–4), verbal response (1–5), and motor response (1–6). GCS_{total} scores are categorized as three severity levels: 3–8 = severe injury, 9–12 = moderate injury and 13–15 = minor injury [4].

Magnitude of early neurological deterioration was defined as a GCS score change that decreased 1 or more points from the prehospital GCS score to the ED GCS score. For example, a change in the GCS score from 14 (prehospital) to 12 (ED) would represent a neurological deterioration magnitude equal to -2.

The Trauma Mortality Prediction Model (TMPM), based on the AIS, measures the probability of mortality. This model identifies the five worst injuries for the patient, then factors into the calculations the interaction of the two worst injuries and whether these injuries were in the same body region [11,18,21,32]. Estimates of the discrimination ability of the TMPM were superior to the ICD-9 Injury Severity Score (ICISS) and Single Worst Injury (SWI) injury severity models (ROC, TMPM = 0.880 [95% CI = 0.876–0.883]; ROC, ICISS = 0.850 [95% CI = 0.846–0.855]; ROC, SWI = 0.862 [95% CI = 0.858–0.867]) [18].

3.3. Data analysis

To determine the proportion of patients whose GCS score deteriorated from prehospital to ED, we coded a variable that indicated whether the GCS score decreased or stayed the same or increased from prehospital to ED assessment. We then examined the proportion of patients whose GCS score decreased across relevant covariates to determine factors associated with early neurological deterioration. Chi-square tests and *t*-tests examined the association of covariates with GCS decrease. We performed a logit transformation of TMPM-AIS scores to convert the probability of mortality to a more normal distribution. Following this logit transformation, we examined factors associated with early neurological deterioration. For this examination, we constructed a logistic regression model to adjust for age, gender, head AIS_{max}, logit transformed TMPM-AIS probability of mortality, year, hospital type and bed size, with GCS decrease as the outcome variable and cluster-corrected standard errors for grouping of patients in the various trauma centers.

To determine the magnitude of early neurological deterioration and the association with the severity of brain injury, we calculated the head AIS_{max} score for each patient and used the highest score as a marker for overall head injury severity. Due to the small number of patients with head AIS_{max} scores of 6 (n = 32), we combined them with patients who had a head AIS_{max} score of 5 (n = 5116). Because the mean and median scores and measures of variability were of limited utility due to the peaked nature of the distribution, we created an ordinal variable that was based on the following categories: GCS decrease > 1 point, GCS decrease = 1 point, no GCS change, GCS increase = 1 point and GCS increase > 1 point. We then created an ordinal logistic regression model with cluster-corrected standard errors for the trauma facility and included this ordinal variable as a predictor variable in the model along with age, gender, logit of the TMPM-AIS probability of mortality, year, and hospital type and bed size.

A p-value < 0.05 was significant in all statistical analyses. All data analyses were conducted using Stata IC, version 13 (Stata Corporation, College Station, TX).

4. Results

4.1. Sample description

There were 144,678 patients who met our inclusion criteria. However, due to missing GCS scores, we eliminated 52,792 patients. Our final sample included 91,886 patients whose mean age was 77 years, and who were primarily white and non-Hispanic with equivalent proportions of men and women. Of the 91,886 patients in our sample, 14,991 (15.8%) died, including 31% with early neurological deterioration. Table 1 presents the demographics of the TBI patients in the NTDB RDS for the years selected, including the total number, those included in this study, and those eliminated due to the missing GCS data.

4.2. Early neurological deterioration

Of the 91,886 patients for whom complete data were available, 13,913 (15.1%) experienced early neurological deterioration. Significant deterioration began at age 80 and continued through the upper boundaries of age. Logistic regression, adjusted for age, gender, head AIS_{max} score, increased TMPM probability of death, hospital size and type, and admission year, revealed that age, gender, head AIS_{max}, and probability of death were associated with early neurological deterioration (Table 2). Beginning at age 80 years, there was a significant increase in the odds of GCS deterioration over the referent group (ages 65–69) ranging from 13% to 36%. Men had slightly higher odds of experiencing early neurological deterioration compared to women. Compared to patients with mild head injury severity (AIS_{max} = 1), those with severe (AIS_{max} = 4), and critical/unsurvivable (AIS_{max} = 5, 6) severity were 40% and 82%, respectively, more likely to experience neurological deterioration.

Only 254 (<1%) patients from our total sample presented a history of long-term anticoagulant/antiplatelet/antithrombotic therapy (LTAT). Of these, 41 (16.1%) experienced early neurological deterioration, compared to 213/254 (83.9%) patients with LTAT and no deterioration. The proportion of patients with early neurological deterioration was comparable among patients who presented with and without a history of LTAT (16.1% versus 15.1%, respectively). LTAT was not associated with early neurological deterioration ($X^2[1] = 0.1983$, $p = 0.656$).

4.3. Magnitude of early neurological deterioration and brain injury severity

Increasing age, male gender, increased TMPM probability of death, and head AIS 4_{max} and AIS $5/6_{max}$ predicted significant odds of neurological deterioration (Table 3).

5. Discussion

We determined the extent, magnitude, and factors associated with early neurological deterioration in brain-injured older adults, a gap in the scientific literature relative to age and gender. Our results revealed associations of age and gender differences with the frequency and magnitude of early neurological deterioration. Compared with previous studies, 7.1% of the patients in our study experienced a magnitude of early deterioration ⩾ 2 GCS points, <9% reported previously [27] and consistent with other investigators reporting degrees of early neurological changes from prehospital to ED [3,25].

LTAT was not associated with early neurological deterioration. Effects of LTAT on mortality have been widely reported, with conflicting results [7,19,20,22,29,33,34,38]. However, none of these studies examined deterioration during the prehospital to ED period. Several factors might explain the absence of early neurological deterioration among patients taking LTAT, including the specific type of anticoagulant therapy and the therapeutic level of the drug [19,33,34]. Additionally, slower evolution of a brain bleed and the larger intracranial space due to atrophic changes of the brain might have allowed for the accumulation of a substantial amount of blood and edema before the effect was large enough to produce a drop in the GCS score.

Comparisons of early neurological deterioration are difficult because earlier studies reported frequency of deterioration relative to GCS scores [25,27], whereas we reported frequency relative to head AIS_{max} scores in order to examine neurological deterioration relative to actual anatomic derangement. In our study, the odds of early neurological deterioration increased with each one-point increase in head AIS_{max} score, beginning with AIS 4_{max} scores. Because GCS scores reflect the patient's behavioral response to injury rather than the anatomic derangement, some non-life-threatening conditions such as concussion might alter the GCS score for a short period, followed by a return to normal, thereby accounting for the improvement noted during the prehospital to ED GCS assessment.

This study has implications for practice, education, research, and policy. From a practice perspective, identifying early neurological deterioration and acting aggressively on opportunities for definitive care before terminal herniation syndromes occur may lead to improved outcomes [4]. Multiple mainstays exist for optimum clinical management of patients with a possible TBI. One is early and thorough neurological assessment prehospital and in the ED. A second is rapidly using assessment data to guide therapy. This may include evaluation and observation in the acute care setting through critical care admission for mechanism-based therapies to resuscitate and rescue from life-threatening brain injury. A third is identifying early indications of evolving serious injury and predictive value of neurological/clinical outcomes. These data are obtained from accurate and consistent assessment, including GCS documentation and vital sign patterns following brain trauma. When interpreted in context, alterations in blood pressure, heart rate, and respiratory drive complement neurological assessment and potentially predict outcome. This interpretation can identify urgency in patient transport to an appropriate level of rapid, definitive care.

Patients with suspected TBIs are often admitted directly to a trauma service, evaluated for a TBI, and treated accordingly. However, asymptomatic patients with a seemingly benign mechanism of injury, such as a ground level fall, may be overlooked by prehospital providers and ED nurses as having a possible TBI. The innocuous appearance of such injuries may divert the attention of ED staff to a diagnostic workup to determine the etiology of the fall and treat other visible injuries, while overlooking a neurological assess-

Table 1
Trauma sample demographics.

	All TBI Cases Age ⩾ 65	Excluded: Cases Missing GCS Change Prehospital to ED	Included: Cases With GCS Change Prehospital to ED
N	144,678	52,792	91,886
Female	72,476 (50.1%)	27,630 (52.3%)	44,846 (48.8%)
Mean (SD) Age	77.1 (7.2)	77.4 (7.1)	76.9 (7.2)
Race			
White	118,200 (81.7%)	42,927 (81.3%)	75,273 (81.9%)
Black or African American	8212 (5.7%)	2957 (5.6%)	5255 (5.7%)
Asian	4383 (3.0%)	1362 (2.6%)	3021 (3.3%)
Other	7019 (4.9%)	2440 (4.6%)	4579 (5.0%)
Ethnicity			
Hispanic or Latino	7310 (5.1%)	2639 (5.0%)	4671 (5.1%)
Non-Hispanic or Latino	96,117 (66.4%)	33,396 (63.3%)	62,721 (68.3%)
AIS Head Maximum Score			
Minor (1)	2995 (2.1%)	1017 (1.9%)	1978 (2.2%)
Moderate (2)	29,777 (20.6%)	9347 (17.7%)	20,430 (22.2%)
Serious (3)	25,198 (17.4%)	9550 (18.1%)	15,648 (17.0%)
Severe (4)	67,692 (46.8%)	27,474 (52.0%)	40,218 (43.8%)
Critical or Unsurvivable (5 or 6)	7498 (5.2%)	2035 (3.9%)	5463 (6.0%)
Mean (SD) TMPM-AIS Probability of Death	0.084 (0.146)	0.071 (0.122)	0.091 (0.158)
ISS			
Mild (1–8)	35,002 (24.2%)	12,204 (23.1%)	22,798 (24.8%)
Moderate (9–15)	41,509 (28.7%)	16,087 (30.5%)	25,422 (27.7%)
Severe (16–24)	40,982 (28.3%)	15,760 (29.9%)	25,222 (27.5%)
Very Severe (⩾ 25)	25,010 (17.3%)	7676 (14.5%)	17,334 (18.9%)
Mortality	14,525 (11.2%)	4132 (8.8%)	10,393 (12.6%)
Hospital Teaching Status			
Community	64,137 (44.3%)	23,352 (44.2%)	40,785 (44.4%)
Non-Teaching	26,144 (18.1%)	10,300 (19.5%)	15,844 (17.2%)
University	54,397 (37.6%)	19,140 (36.3%)	35,257 (38.4%)
Hospital Bed Size			
⩽200	11,823 (8.2%)	5088 (9.6%)	6735 (7.3%)
201–400	43,956 (30.4%)	15,971 (30.3%)	27,985 (30.5%)
401–600	43,972 (30.4%)	15,380 (29.1%)	28,592 (31.1%)
>600	44,927 (31.1%)	16,353 (31.0%)	28,574 (31.1%)
Year			
2009	30,423 (21.0%)	11,867 (22.5%)	18,556 (20.2%)
2010	33,839 (23.4%)	12,478 (23.6%)	21,361 (23.3%)
2011	37,978 (26.3%)	13,630 (25.8%)	24,348 (26.5%)
2012	42,438 (29.3%)	14,817 (28.1%)	27,621 (30.1%)
GCS Deterioration	–	–	13,913 (15.1%)
Magnitude of GCS Decrease			
No GCS Change or GCS Increase	–	–	77,973 (84.9%)
GCS Decrease = 1	–	–	7426 (8.1%)
GCS Decrease ⩾ 2	–	–	6487 (7.1%)

Note: All reported data are listed as n(%) unless otherwise noted. In some cases due to missing data in the demographic covariate, sums will not equal the total. Percentages are calculated with the within demographic covariate missing values included in the denominator.
GCS is Glasgow Coma Scale score.

ment. The focus away from possible neurological injury was evidenced in the large number of missing GCS scores (36.5%) in our eligible population, even though three-quarters had life-threatening brain injuries. The need for vigilance in evaluating neurological status among injured older adults is underscored by the task force that developed Geriatric Emergency Department Guidelines [17]. The unanswered question is the frequency with which the GCS score should be assessed in patients who have an injury mechanism that might cause a TBI but *who have not yet been diagnosed with a TBI*. No scientific evidence was found to answer this question. However, based on our findings, a focused neurological assessment should be done, *at a minimum*, at the injury scene and upon arrival in the ED and thereafter as indicated. Nurses should monitor the trending of neurological assessments and vital signs.

GCS score assessment to screen for TBI has long been the standard of practice for prehospital providers and ED staff in the United States and many other countries. However, several studies and reviews point to mixed findings regarding the accuracy of the GCS and competency of staff performing GCS assessments to detect early TBIs [13,40]. Ongoing education and frequent competency assessment for prehospital providers and ED nursing staff should be conducted to ensure that GCS scoring is performed correctly. Additional studies using rigorous methods to evaluate interrater agreement of the GCS are also needed.

Additional research is needed, including comparative analyses of alternate instruments for point-of-care assessment of neurological deterioration. The use of the FOUR scale shows promise as one alternative for this purpose [28].

From a policy perspective, all emergency departments should consider adopting a policy for a thorough head to toe assessment of older adults who fall, such as that described in the Geriatric Emergency Department Guidelines [17]. Furthermore, prehospital emergency service provider agencies should incorporate a GCS

Table 2
Factors associated with GCS deterioration.

	Adjusted Odds Ratio (95% CI)[a]	p-value
Age		
65–69	Referent	–
70–74	1.01 (0.94–1.09)	0.721
75–79	1.05 (0.99–1.12)	0.135
80–84	1.13 (1.06–1.20)	<0.001
85–89	1.25 (1.16–1.34)	<0.001
⩾90	1.36 (1.26–1.48)	<0.001
Male	1.07 (1.03–1.12)	0.001
AIS[b] Head Maximum Score		
Minor (1)	Referent	–
Moderate (2)	1.10 (0.95–1.27)	0.224
Serious (3)	1.01 (0.87–1.17)	0.886
Severe (4)	1.40 (1.21–1.63)	<0.001
Critical or Unsurvivable (5 or 6)	1.82 (1.50–2.22)	<0.001
Logit of TMPM-AIS Probability of Death[c]	1.17 (1.14–1.20)	<0.001
Year	1.00 (0.98–1.02)	0.709
Hospital Teaching Status		
Community	Referent	–
Non-Teaching	1.04 (0.95–1.13)	0.385
University	1.06 (0.98–1.15)	0.130
Hospital Bed Size		
⩽200	Referent	–
201–400	1.05 (0.95–1.17)	0.330
401–600	0.98 (0.87–1.09)	0.686
>600	0.98 (0.88–1.10)	0.720

[a] Standard errors are adjusted for clustering of subjects within 768 hospital facilities.
[b] AIS, Abbreviated Injury Scale.
[c] TMPM-AIS, Trauma Mortality Prediction Model - Abbreviated Injury Scale Probability of Death.

Table 3
Factors associated with magnitude of GCS deterioration (ordinal logistic regression model with outcomes of and ordered: GCS increase or no change, GCS decrease = 1, GCS decrease ⩾ 2).

	Adjusted Odds Ratio (95% CI)[a]	p-value
Age		
65–69	Referent	–
70–74	1.01 (0.94–1.09)	0.749
75–79	1.05 (−0.98 to 1.12)	<0.177
80–84	1.12 (1.05–1.19)	0.001
85–89	1.23 (1.15–1.32)	<0.001
⩾90	1.33 (1.23–1.45)	<0.001
Male	1.07 (1.03–1.12)	0.001
AIS Head Maximum Score		
Minor (1)	Referent	–
Moderate (2)	1.11 (0.96–1.28)	0.168
Serious (3)	1.01 (0.87–1.17)	0.920
Severe (4)	1.41 (1.22–1.63)	<0.001
Critical or Unsurvivable (5 or 6)	1.98 (1.63–2.40)	<0.001
Logit of TMPM-AIS Probability of Death	1.18 (1.15–1.21)	<0.001
Year	0.99 (0.97–1.01)	0.557
Hospital Teaching Status		
Community	Referent	–
Non-Teaching	1.04 (0.95–1.13)	0.393
University	1.06 (0.99–1.15)	0.116
Hospital Bed Size		
⩽200	Referent	–
201–400	1.05 (0.94–1.17)	0.373
401–600	0.97 (0.87–1.09)	0.614
>600	0.98 (0.88–1.10)	0.739

[a] Standard errors are adjusted for clustering of subjects within 768 hospital facilities.

assessment as part of prehospital care for all patients who report an injury that might cause a brain bleed, regardless of whether a paramedic or other provider with basic emergency medical technician training provides care.

Our use of secondary data and a non-representative sample limits the generalizability of our findings. The number of hospitals submitting data to the NTDB has grown from 682 in 2009 to 805 in 2012, with non-weighted representation from most regions of the United States [2]. Missing prehospital and ED GCS data were a concern; therefore, these patients were excluded from analysis. Gender, racial, and ethnic distribution and mean age were equivalent in the total population, study sample, and patients whose records we eliminated due to missing data. However, patients in the excluded group were less severely injured and experienced lower mortality compared to our final sample.

Prehospital records in the NTDB are date-stamped, but not time-stamped, so we were unable to time index prehospital GCS recordings. We could not determine association of neurological deterioration and its magnitude with length of the prehospital interval. However, previous research suggested that time interval did not significantly influence early neurological deterioration [15].

6. Conclusions

A modest proportion of older adults with TBIs experienced early neurological deterioration. Frequency and greater magnitude of neurological deterioration occurred more frequently in men. Age, gender, brain injury severity, and mortality probability were predictors of early neurological deterioration. As the proportion of older adults continues to grow, we can expect a proportional increase in the number of TBIs. Early recognition of neurological deterioration and timely definitive treatment can mitigate the effects of brain injury. Prehospital, ED, and other care providers must assess injured older adults early and frequently, being alert and proactive to any indicators of brain injury.

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