Blunt Head Injury in the Elderly: Analysis of the NEXUS II Injury Cohort

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Background: Changes with aging make older patients vulnerable to blunt head trauma and alter the potential for injury and the injury patterns seen among this expanding cohort. High-quality care requires a clear understanding of the factors associated with blunt head injuries in the elderly. Our objective was to develop a detailed assessment of the injury mechanisms, presentations, injury patterns, and outcomes among older blunt head trauma patients.

Methods: We conducted a planned secondary analysis of patients aged 65 or greater who were enrolled in the National Emergency X-Radiography Utilization Study (NEXUS) Head Computed Tomography validation study. We performed a detailed assessment of the demographics, mechanisms, presentations, injuries, interventions, and outcomes among older patients.

Results: We identified 3,659 patients aged 65 years or greater, among the 11,770 patients enrolled in the NEXUS validation study. Of these older patients, 325 (8.9%) sustained significant injuries, as compared with significant injuries in 442 (5.4%) of the 8,111 younger patients. Older females (1,900; 51.9%) outnumbered older males (1,753; 47.9%), and occult presentations (exhibiting no high-risk clinical criteria beyond age) occurred in 48 (14.8%; 95% confidence interval (CI) 11.1 to 19.1) patients with significant injuries. Subdural hematomas (377 discreet lesions in 299 patients) and subarachnoid hemorrhages (333 discreet instances in 256 patients) were the most frequent types of injuries occurring in our elderly population. A ground-level fall was the most frequent mechanism of injury among all patients (2,211; 69.6%), those sustaining significant injuries (180; 55.7%), and those who died of their injuries (37; 46.3%), but mortality rates were highest among patients experiencing a fall from a ladder (11.8%; 4 deaths among 34 cases [95% CI 3.3% to 27.5%]) and automobile versus pedestrian events (10.7%; 16 deaths among 149 cases [95% CI 6.3% to 16.9%]). Among older patients who required neurosurgical intervention for their injuries, only 16.4% (95% CI 11.1% to 22.9%) were able to return home, 32.1% (95% CI 25.1% to 39.8%) required extended facility care, and 41.8% (95% CI 34.2% to 49.7%) died from their injuries.

Conclusions: Older blunt head injury patients are at high risk of sustaining serious intracranial injuries even with low-risk mechanisms of injury, such as ground-level falls. Clinical evaluation is unreliable and frequently fails to identify patients with significant injuries. Outcomes, particularly after intervention, can be poor, with high rates of long-term disability and mortality. [Ann Emerg Med. 2024;■:1-10.]

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INTRODUCTION

In recent years, the proportion of the US population over the age of 65 years has grown nearly 5 times faster than the general population and now accounts for one-sixth of the overall population.[1] This trend is expected to accelerate as "Baby Boomers" age, while younger populations decrease.[2] Accompanying the growth in the elderly population is an increase in traumatic injuries and a corresponding need for specialized trauma care.[3,4]

Traumatic brain injuries (TBI) are particularly prevalent among elderly trauma patients, and recent estimates suggest that older patients account for 48% to 56% of hospitalization for TBI.[5] Although TBI in the elderly has clear clinical impact, specific relevant information remains limited.[6]

The goal of this descriptive study is to present prospective information on the demographics, mechanisms, presentations, injuries, interventions, and outcomes of traumatic blunt head injury among the elderly through a planned secondary analysis of data from the National Emergency X-Radiography Utilization Study (NEXUS) Head Computed Tomography (CT) validation study.[7] In

Editor's Capsule Summary

What is already known on this topic

Validated clinical decision rules for blunt head trauma identify older adults as higher risk than younger patients and guide computed tomography (CT) scan use.

What question this study addressed

What are the clinical presentations and outcomes of older head-injured emergency department (ED) patients?

What this study adds to our knowledge

Using data from 3,659 ED patients aged 65 years and older who received a CT scan for blunt head trauma, serious injuries were more common among older than younger adults (8.9% vs. 5.4%). Older adults had no high-risk features other than age based on the NEXUS (15%) and Canadian CT Head criteria (21%).

How this is relevant to clinical practice

These results support routine head CT imaging in older head-injured patients.

particular, we wanted to examine the prevalence of occult injury among elderly head injury victims, how mechanisms of injury are related to injury severity, and the application of cervical imaging among older head-injured patients.

MATERIALS AND METHODS

We performed this secondary analysis of all patients aged 65 years or greater who were enrolled in the NEXUS Head CT decision instrument validation study.[7,8] The primary goal of the NEXUS study was to validate the performance of the previously derived NEXUS head CT decision instrument, with comparisons to the performance of the Canadian CT Head rule.[9] Details of the methods used in our validation study are described elsewhere, and briefly summarized here.[7,8] We conducted the original validation study from April 2006 through December 2015. Our work is compliant with STROBE guidelines, and we have included a completed STrengthening the Reporting of OBservational studies in Epidemiology (STROBE) checklist in our supplementary materials (available at http://www.annemergmed.com).

Setting

We conducted our original study at 4 emergency departments (EDs) (Antelope Valley Medical Center, Lancaster, CA; San Francisco General Hospital, San Francisco CA; UCLA Ronald Reagan Medical Center, Los Angeles, CA; UCSF Fresno Community Regional Medical Center, Fresno, CA) representing urban, suburban, and rural communities and community and academic hospitals. Each participating center obtained institutional review and approval for the study, including a waiver of informed consent.

Patients

Physicians at participating centers enrolled consecutive blunt trauma patients who underwent head CT imaging. We left imaging decisions to the discretion of the treating physicians and specifically cautioned providers against using the decision instrument to determine which patients required imaging. We initiated enrollment when the treating physician ordered CT head imaging. At that time, study coordinators provided the clinicians with survey forms that allowed them to document limited clinical and demographic information for each patient. We excluded patients who sustained penetrating trauma, those with delayed presentations (>24 hours after their injury), those receiving imaging for indications other than blunt trauma, and patients with known injuries transferred from an outside hospital.

Data Collection

We have described our data collection methods in detail elsewhere.[7,8] Briefly, we asked clinicians to provide demographic information for each patient (age, sex, race, and ethnicity) as well as their assessments for each of the criterion included in the NEXUS and Canadian decision instruments. Each criterion was recorded as present, absent, or unable to be assessed. We designated the unassessed criteria as abnormal to maximize safety and ensure that patients were not given low-risk classification on the basis of missing data. We allowed clinicians to bypass data collection and proceed to immediate imaging if they felt that even a minimal delay might be harmful to the patient. We labeled such patients as unstable and excluded them from low-risk classification.

Outcome Assignment

Radiologists, unaware of demographic information and details of the criterion assessments, reviewed and recorded their interpretation of the CT imaging studies. We classified patients into 2 categories: uninjured (no intracranial injuries) versus any intracranial injury. We then subdivided intracranial injury patients into significant injury versus no significant injury categories and finally the significant injury group into neurosurgical intervention versus no neurosurgical intervention groups. We defined significant injury using the definitions provided by Stiell et al,[9] which includes all injuries found on head CT imaging except for solitary small contusions, localized subarachnoid hemorrhages less than 1 millimeter thick, subdural hematoma less than 4 millimeters thick, isolated pneumocephaly, and closed or depressed skull fractures that do not violate the inner table. We defined the need for neurosurgical intervention as the occurrence of any of the following within 7 days of injury: 1) death due to head injury, 2) need for craniotomy, 3) elevation of skull fracture, 4) intubation related to head injury, and 5) intracranial pressure monitoring.

We based the clinical assessment of skull fracture (as opposed to the radiographic assessment) on the responses to the criterion assessment, which specifically requested clinicians to determine whether each patient exhibited evidence of skull fracture, including signs of depressed, basilar, or open fracture. We based our ultimate determination on the presence or skull fracture on final radiographic interpretations.

Abstraction of Radiographic Reports

Three physician investigators independently abstracted each of the CT imaging reports generated during the study. Abstractions included the identification and classification of injury type (subdural hematoma, epidural hematoma, nonspecific extra-axial injury, subarachnoid hemorrhage, parenchymal hemorrhage, parenchymal contusion, diffuse axonal injury, diffuse edema, nondisplaced skull fracture, displaced skull fracture, depressed skull fracture, or basilar skull fracture). Abstractors also recorded the location(s) of each injury (frontal, temporal, parietal, occipital, falx, tentorium, Sylvian fissure, brainstem, cerebellum, or intraventricular). Where present, reviewers recorded presence of pneumocephalus, midline shift, or herniation.

We conducted redundant reviews on a random sample of 100 radiographic interpretations and classifications to assess inter-rater reliability based on concordance of both classification of injury and injury location(s).

Abstraction of Medical Records

Three of our centers (Antelope Valley, UCSF, UCLA) participated in assessments of mechanism of injury, long-term outcomes, and cervical spine imaging assessments. In accordance with current standards, we employed trained observers at each site, blind to our final outcomes, to review the medical records for each enrolled patient and record specific predefined details, including the mechanism of injury, whether each patient received cervical spine imaging in conjunction with their head CT imaging, whether the imaging demonstrated cervical spine injuries, and the results of NEXUS cervical spine screening evaluations among patients with injuries.[10,11] Our reviewers assigned "unknown" designation to data elements that were missing or could not be determined through their reviews.

Abstractors recorded the final discharge disposition (home, skilled nursing facility, inpatient transfer, leaving against medical advice, death, or unknown disposition) for patients who exhibited any intracranial injuries. We conducted redundant reviews on a random subset of 100 medical record abstractions to assess inter-rater reliability using the kappa statistic.

Data Analysis

Sample size estimation. The NEXUS Head CT validation study was designed to provide a precision of 1% for the measurement of the instrument's sensitivity in detecting injuries that required neurosurgical intervention, necessitating enrollment of 368 patients with such injuries.[7,8] Our secondary analysis is descriptive in nature, entails no hypothesis testing, and includes all patients aged 65 years or older from the original study. We provide confidence intervals for select outcomes to illustrate the precision of our measurements.

Data analysis. In this descriptive study we present point measures and associated unadjusted confidence intervals. We recorded and processed our data using Microsoft Excel (Redmond, Washington).

RESULTS

Among the total enrollment of 11,770 patients, we identified 1,352 patients with any intracranial injury, 767 patients with significant intracranial injuries, and 420 cases requiring neurosurgical intervention. Our cohort included 3,659 (31.1%) patients aged 65 years or greater. In total, 500 (13.7%; 95% confidence interval (CI) 12.6% to 14.8%) elderly patients had evidence of injury on their CT imaging, including 325 patients who had significant intracranial injuries (8.9% of all elderly patients [95% CI 8.0% to 9.9%], 42.4% of all significantly injured patients of any age [95% CI 38.8% to 46.0%], 65.0% of the elderly injured patients [95% CI 60.6% to 69.2%]), 177 patients who required intervention (4.8% of all elderly cases [95% CI, 4.2% to 5.6%], 42.1% of all patients of any age requiring intervention [95% CI 37.4% to 47.0%], and 35.4% of injured elders [95% CI 31.2% to 39.8%]), and 81 patients who died (2.2% of all elderly patients [95% CI 1.8% to 2.7%], 10.6% of all significantly injured patients of any age [95% CI 8.5% to 13.0%], and 45.8% of older patients requiring intervention [95% CI 38.3% to 53.4%]). Among all older patients, females (1,900 [51.9%]) outnumbered males (1,753 [47.9%]), but males were more likely than females to sustain any intracranial injury (300 males [60.0%] versus 199 females [39.8%] with one unknown sex), significant injury (202 males [62.2%] versus 123 females [37.8%]) injury requiring intervention (114 males [64.8%] versus 62 females [35.2%]), or death (54 males [66.7%] versus 27 females [33.3%]). Table 1 presents details of the demographic characteristics of our enrolled elderly population.

Due to age criteria, all of our elderly patients would have been classified as high-risk by the NEXUS and Canadian Head CT decision instruments. In addition to age, 77 (15.4%; 95% CI 12.3% to 18.9%) of the injured patients exhibited no other NEXUS criteria, including 48 of the 325 patients (14.8%; 95% CI 11.1% to 19.1%) with significant injuries and 20 (11.3%; 95% CI 7.0% to 16.9%) patients who required intervention. Similarly, 128 injured patients (25.6%; 95% CI, 21.8% to 29.7%) exhibited no other Canadian “high risk” criteria, including 68 patients with significant injuries (20.9% of significantly injured patients [95% CI 16.6% to 25.8%]) and 24 patients (13.6%; 95% CI 8.9% to 19.5%]) requiring neurosurgical intervention. An abnormal level of alertness was documented in 187 (57.5%) patients with significant injuries and 128 (72.3%) requiring intervention, making it the most prevalent finding among these groups. Our supplementary materials provide a detailed summary of the presenting signs, symptoms, and risk factors among elderly patients. Physicians indicated that they detected signs of skull fracture in 27 of 87 elderly patients with skull fracture (sensitivity of 31.0% [95% CI 21.5% to 41.9%]). They reported no evidence of skull fracture in 3,495 of 3,579 patients who did not sustain skull fractures (specificity of 97.7% [95% CI 97.1% to 98.1%]).

Subdural hematomas (377 discreet lesions in 299 patients) and subarachnoid hemorrhages (333 discreet instances in 256 patients) were the most frequent types of injuries occurring in our elderly population. These injuries were present in 68.8% (55/80) of patients who died, but only a minority of patients with these injuries died (subarachnoid hemorrhage in 74/333 [22.2%]; subdural hematoma in 72/377 [19.1%]). Alternatively, although evidence of herniation was present in a small minority of

Table 1. Demographic characteristics of elderly blunt trauma patients.*

Demographic Categories	All Patients	Uninjured	Any Injury	Significant Injury	Intervention
N	3,659	3,159	500	325	177
Age, y					
Median	81	81	80	81	81
IQR	73 to 87	73 to 88	73 to 86	73 to 86	73 to 87
Range	65 to 104	65 to 104	65 to 99	65 to 98	65 to 96
Sex (N, %)					
Male	1,753 (47.9%)	1,453 (46.0%)	300 (60.0%)	201 (61.8%)	114 (64.4%)
Female	1,900 (51.9%)	1,701 (53.8%)	199 (39.8%)	123 (37.8%)	62 (35.0%)
Unknown	6 (0.2%)	5 (0.2%)	1 (0.2%)	1 (0.3%)	1 (0.6%)
Race (N, %)					
Asian	264 (7.2%)	204 (6.5%)	60 (12.0%)	45 (13.8%)	26 (14.7%)
Black	189 (5.2%)	170 (5.4%)	19 (3.8%)	12 (3.7%)	7 (4.0%)
Middle Eastern	178 (4.9%)	155 (4.9)	23 (4.6%)	9 (2.8%)	7 (4.0%)
Native American	1 (0.03%)	1 (0.03%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Other	184 (5.0%)	159 (5.0%)	25 (5.0%)	20 (6.2%)	8 (4.5%)
White	2,836 (77.5)	2,463 (78.0%)	373 (74.6%)	239 (73.5%)	129 (72.9%)
Unknown	7 (0.2%)	7 (0.2%)	0 (0.0%)	0 (0.0%)	0 (0.0%)
Ethnicity (N, %)					
Hispanic	233 (6.4%)	196 (6.2%)	37 (7.4%)	29 (8.9%)	14 (7.9%)
Non-Hispanic	3,419 (93.4%)	2,956 (93.6%)	463 (92.6%)	296 (91.1%)	163 (92.1%)
Unknown	7 (0.2%)	7 (0.2%)	0 (0.0)	0 (0.0%)	0 (0.0%)

IQR, interquartile range.

*Note: Populations described in each column of the table represent a subset of the preceding column.

cases 29/500 (5.8%), it was the finding associated with the highest mortality rate 18/29 (62.1%). Table 2 presents the distribution of cases with specific CT findings based on the overall severity of injury.

Table 3 presents the distribution of different injury levels for different injury mechanisms. Ground-level falls, including falls secondary to syncope, occurred in 69.6% (2,211/3,175) of elderly presentations, including 59.2% (295/498) of patients with any intracranial injury, 55.7% (180/323) of patients with significant injuries, 53.4% (94/176) of patients requiring intervention, and 45.7% (37/81) of patients who died from their injuries. Table 4 summarizes injury severity by mechanism. We found that ground-level fall was the mechanism associated with the greatest number of deaths (45.7%; 37 of 81 cases), but the associated mortality rate of 2.1% (37 of 2,211 cases [95% CI 1.2% to 2.3%]) was relatively small compared to mortality rates (MR) for fall from a ladder (MR = 11.8%; 4/34 cases [95% CI 3.3% to 27.5%]) and automobile versus pedestrian events (MR=10.7%; 16/149 cases [95% CI 6.2% to 16.9%]). Males were more likely to sustain injuries than females across all injury levels. They accounted for 300 (60.0%) of the 500 cases with any injury, 202 (62.2%) of the 325 patients with significant injury, 114 (64.4%) of 177 patients requiring intervention, and 54 (67.5%) of 80 patient who died.

Our long-term outcomes study included 3,315 elderly patients, 458 (14.6%) of whom had intracranial injuries. Overall, 39.5% (181/458) of patients exhibiting any form of intracranial injury were able to return home, 34.7% (159/458) required placement in an extended care facility, and 17.7% (81/458) died from their injuries. Table 5 summarizes our hospital discharge dispositions by injury status. Among patients with insignificant injuries, 55.7% (93/167 [95% CI 47.8% to 63.4%]) were able to return home, 35.3% (59/167 [95% CI 28.1% to 43.1%]) required facility care, and 3.6% (6/167 [95% CI 1.3% to 7.7%]) died. In comparison, among patients requiring interventions for their head injury, only 16.4% (27/165 [95% CI 11.1% to 22.9%]) were able to return home, 32.1% (53/165 [95% CI 25.1% to 39.8%]) required facility care, and 41.8% (69/165 [95% CI 34.2% to 49.7%]) died of their injuries.

Our long-term outcome cohort included 2,196 (70.0%) patients who had experienced ground-level falls, of whom 280 (12.8%) sustained intracranial injuries and 89 (4.1%) required neurosurgical intervention. Thirty-six (12.9%) of these injured patients, including 8 (2.9%) who required neurosurgical intervention, exhibited no risk criteria other than age.

Clinicians ordered cervical spine imaging on 54.7% (1,738/3,178) of all elderly head injury patients, and 80.8% (143/177) of patients with head injuries requiring intervention. Imaging identified cervical spine injuries in 77 patients (2.4%), including injuries in 22 (6.8%) patients requiring neurosurgical intervention for their head injury. Among patients with ground-level falls, imaging identified cervical spine injuries in 31 patients (1.4%), including 3 (3.2%) patients who required intervention for their intracranial injury. The NEXUS c-spine decision instrument assigned a high-risk status to all 15 patients requiring spine interventions (operative repair or halo placement), yielding a sensitivity of 100% (95% CI 78.2%

Table 2. Distribution of cases based on initial CT findings and overall injury severity.*

CT Findings/Injuries	All Cases (N=500)	Cases Involving One or More Significant Injuries (N=325)	Cases Requiring Intervention (N=177)	Cases Ending in Death (N=81)
Findings				
Shift	93 (18.6%)	92 (28.3%)	74 (41.8%)	34 (42.0%)
Herniation	29 (5.8%)	28 (8.6%)	27 (15.3%)	18 (22.2%)
Specific Injuries				
Contusions	51 (10.2%)	19 (5.8%)	6 (3.4%)	1 (1.2%)
Epidural hematoma	19 (3.8%)	18 (5.5%)	11 (6.2%)	4 (4.9%)
Extra-axial bleed†	7 (1.4%)	4 (1.2%)	0 (0.0%)	0 (0.0%)
Parenchymal bleed	142 (28.4%)	117 (36.0%)	71 (40.1%)	38 (46.9%)
Subarachnoid hemorrhage	256 (51.2%)	180 (55.4%)	105 (59.3%)	55 (67.9%)
Subdural hematoma	299 (59.8%)	234 (72.0%)	130 (73.4%)	55 (67.9%)
Ventricular bleed	63 (12.6%)	57 (17.5%)	39 (22.0%)	25 (30.9%)

*Patients with multiple injuries are counted multiple times in the table, once for each injury.
†Unspecified extra-axial bleed.

Table 3. Mechanism of injury in elderly patients by injury status.

Mechanism	All Patients (N=3,175)	Uninjured (N=2,677)	Any Injury (N=500)	Significant Injury (N=323)	Requiring Intervention (N=176)	Injuries Resulting in Death (N=81)
Assault	23 (0.7%)	15 (0.6%)	8 (1.6%)	5 (1.5%)	1 (0.6%)	0 (0.0%)
Automobile versus pedestrian	149 (4.7%)	96 (3.6%)	53 (10.6%)	40 (12.4%)	28 (15.9%)	16 (19.8%)
Bicycle injuries						
Automobile versus bicycle	32 (1.0%)	22 (0.8%)	10 (2.0%)	3 (0.9%)	1 (0.6%)	0 (0.0%)
Bicycle accident, other	45 (1.4%)	34 (1.3%)	11 (2.2%)	8 (2.5%)	2 (1.1%)	0 (0.0%)
Falls						
Fall down stairs	148 (4.7%)	105 (3.9%)	43 (8.6%)	34 (10.5%)	20 (11.4%)	12 (14.8%)
Fall from height	37 (1.2%)	25 (0.9%)	12 (2.4%)	6 (1.9%)	4 (2.3%)	3 (3.7%)
Fall off ladder	34 (1.1%)	19 (0.7%)	15 (3.0%)	13 (4.0%)	8 (4.5%)	4 (4.9%)
Ground-level fall	2,211 (69.6%)	1,916 (71.6%)	295 (59.2%)	180 (55.7%)	94 (53.4%)	38 (46.9%)
Motor vehicle accident	229 (7.2%)	204 (7.6%)	25 (5.0%)	15 (4.6%)	9 (5.1%)	5 (6.2%)
Motorcycle accident	26 (0.8%)	22 (0.8%)	5 (1.0%)	3 (0.9%)	0 (0.0%)	0 (0.0%)
Other	165 (5.2%)	155 (5.8%)	10 (2.0%)	8 (2.5%)	3 (1.7%)	1 (1.2%)
Unknown	76 (2.4%)	64 (2.4%)	13 (2.6%)	10 (3.1%)	5 (2.8%)	2 (2.5%)

to 100.0%) for intervention, and 69 of 77 patients with any injury (sensitivity=89.6%; 95% CI 80.6% to 95.4%). Table 6 describes the 8 patients with cervical spine injuries who were assigned low-risk classification by the NEXUS c-spine tool.

The assessment of our raters revealed that they agreed on the exact number of injuries in 90% of cases and exhibited an intraclass correlation coefficient of 0.90 (95% CI 0.85 to 0.93). Their raw agreements on the types and locations of injuries were 93% and 92%, respectively, with intraclass correlation coefficients of 0.89 (95% CI 0.84 to 0.92) for each categorization. Our reviewers exhibited 97% agreement on c-spine imaging, yielding an inter-rater kappa score of 0.94 (95% CI 0.87 to 0.99), and 100% agreement on the presence of cervical spine injury, yielding a kappa value of 1.0 (95% CI 1.0 to 1.0). Regarding mechanism of injury, our reviewers exhibited raw agreement of 91% with a kappa score of 0.84 (95% CI 0.74 to 0.94).

Table 4. Mechanism of injury by known discharge disposition among patients with any injury.*

Mechanism	Home	Extended Care Facility	Transfer	AMA	Injury-Specific Mortality Rate	Overall Mortality Rate
Assault (n=6)	3 (50.0%)	2 (33.3%)	1 (16.7%)	0 (0.0%)	0 of 8 (0.0%)	0 of 23 (0.0%)
Automobile versus pedestrian (n=48)	15 (31.3%)	14 (29.2%)	3 (6.3%)	0 (0.0%)	16 of 53 (30.1%)	16 of 149 (10.7%%)
Bicycle injuries						
Automobile versus bicycle (n=8)	5 (62.5%)	2 (25.0%)	1 (12.5%)	0 (0.0%)	0 of 10 (0.0%)	0 of 32 (0.0%)
Bicycle accident, other (n=10)	7 (70.0%)	2 (20.0%)	1 (10.0%)	0 (0.0%)	0 of 11 (0.0%)	0 of 45 (0.0%)
Falls						
Fall down stairs (n=43)	15 (34.9%)	9 (20.9%)	6 (14.0%)	0 (0.0%)	12 of 43 (27.9%)	12 of 148 (8.1%)
Fall from height (n=11)	3 (27.3%)	3 (27.3%)	1 (9.1%)	0 (0.0%)	3 of 12 (25.0%)	3 of 37 (8.1%)
Fall off ladder (n = 15)	4 (26.7%)	4 (26.7%)	3 (20.0%)	0 (0.0%)	4 of 15 (26.7%)	4 of 34 (11.8%)
Ground-level fall (n=280)	115 (41.1%)	111 (39.6%)	12 (4.3%)	4 (1.4%)	37 of 295 (12.5%)	37 of 2,211 (1.7%)
Motor vehicle accident (n=22)	6 (27.3%)	10 (45.5%)	1 (4.6%)	0 (0.0%)	5 of 25 (20.0%)	5 of 229 (2.2%)
Motorcycle accident (n=3)	3 (100.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	0 of 4 (0.0%)	0 of 26 (0.0%)
Other (n=4)	3 (75.0%)	0 (0.0%)	0 (0.0%)	0 (0.0%)	1 of 10 (10.0%)	1 of 165 (0.6%)
Unknown (n=8)	2 (25.0%)	2 (25.0%)	2 (25.0%)	0 (0.0%)	2 of 12 (16.7%)	2 of 76 (2.6%)

AMA, against medical advice.
*Among the 3 centers participating in the long-term outcome evaluation.

Table 5. Discharge dispositions by injury level.*

Disposition	Any Injury (N=458)	Insignificant Injury (N=167)	Significant Injury (N=291)	Injury Requiring Intervention (N=165)
AMA	4 (0.9%)	3 (1.8%)	1 (0.3%)	0 (0.0%)
Death	80 (17.5%)	6 (3.6%)	74 (25.4%)	69 (41.8%)
Extended care facility	159 (34.7%)	59 (35.3%)	100 (34.4%)	53 (32.1%)
Home	181 (39.5%)	93 (55.7%)	88 (30.2%)	27 (16.4%)
Transfer	31 (6.8%)	6 (3.6%)	25 (8.6%)	13 (7.9%)
Unknown	3 (0.7%)	0 (0.0%)	3 (1.0%)	3 (1.8%)

*Among the 3 centers participating in the long-term outcome evaluation.

LIMITATIONS

We employed a pragmatic design in our study, with an emphasis on enrolling trauma patients from a variety of different environments. As a consequence, our findings may differ from results observed in more focused settings and more limited environments. For example, nontrauma centers that encounter relatively few blunt injury patients may see few elderly TBI patients overall and are likely to encounter patients with lower acuity as compared with patients triaged to high-level trauma centers. Similarly, hospitals that encounter a high proportion of seriously injured patients may find fewer low acuity patients.

Clinical evaluations and assessments as well as radiographic interpretations and patient management decisions are subject to practitioner variation. Although several hundred physicians participated in our trial, along with several hundred radiologists and traumatologists, their overall performance will likely differ from any single individual or center.

Including neurosurgical intervention as a primary outcome in our study means that our results are vulnerable to variations in practice patterns and the decisions to implement these interventions. Centers with differing neurosurgical support services may have different rates of intervention.

Currently available clinical decision tools uniformly fail to predict head injuries in a significant proportion of elderly trauma patients, leading to calls for CT imaging of all older patients.[12] Our data confirm that occult injuries are not uncommon and that identifying injury in older patients can be challenging. However, it is unclear whether clinicians need to image all older head trauma patients, regardless of the severity of trauma. It is likely that at some level, trivial mechanisms of injury are virtually never associated with

Table 6. Blunt head injury patients with cervical spine injuries who were classified as “low-risk” using the NEXUS C-spine decision instrument.

(a) Misclassifications among patients without intracranial injuries.

Patient	Mechanism	Injuries	Treatment
89-y-old female	Ground-level fall	C1 anterior arch fracture	Aspen collar
73-y-old male	Fall from ladder	C4 inferior end plate fracture without displacement, of indeterminate age	Aspen collar
87-y-old female	Ground-level fall	Old C2 fracture	Aspen collar
89+-y-old female	Motor vehicle accident	Spinous process fractures C3 to C5	None
88-y-old male	Ground-level fall	Type III odontoid fracture with mild displacement; bilateral C1 posterior ring fractures without displacement	Aspen collar
89+-y-old male	Ground-level fall	Transverse nondisplaced fracture through the base of the odontoid; fracture of C5 spinous process and right posterior lamina	Aspen collar

(b) Misclassifications among patients who had intracranial injuries.

Patient	Mechanism	Injuries	Treatment
73-y-old male	Motor vehicle accident	Stable C7 lateral mass fracture	None
87-y-old male	Ground-level fall	C2 body fracture of indeterminate age	None

significant injury. However, defining such trivial injuries is beyond the scope of our study and awaits further research.

It is also important to note that we did not enroll all older blunt injury patients in our study, but only those patients who underwent CT head imaging. Thus, it is possible that we may have failed to detect intracranial injuries in patients who did not undergo imaging, and we may have under estimated injury prevalence. To assess the potential for this type of event, we conducted a separate assessment to determine the potential for verification bias with a precision of 1.0%. As detailed in our prior report, we enrolled 368 blunt trauma patients who did not receive CT head imaging during their evaluation.[7] None of these patients were found to have had intracranial injuries on 3-month follow-up evaluations, yielding a measured potential for verification bias of 0.0% (95% CI 0.0% to 1.0%). An accompanying review of case and trauma logs failed to reveal any instances of missed injuries or injuries requiring neurosurgical intervention among blunt trauma patients who did not have head CT imaging performed on their initial evaluation. Thus, although it is possible that we may have failed to identify significant intracranial injuries in some patients, the overall probability is very low.

The use of direct oral anticoagulants has increased in recent years, and while we tracked overall anticoagulation, we did not specifically track direct oral anticoagulant use. Direct oral anticoagulants appear to be associated with lower risk for traumatic intracerebral hemorrhage than vitamin K antagonists, but still present significant risk and have not been shown to decrease the neurosurgical intervention rate.[13] Thus, it is possible that our study may slightly overestimate the risk of traumatic intracerebral hemorrhage among our elderly patients, but the risk of injury requiring intervention would likely be unchanged.

Tracking long-term outcomes for all older patients is not feasible, and our assessment for potential verification bias in our validation study was not exhaustive. Thus, it is possible that our study failed to capture all injured patients presenting to the participating centers. However, our efforts to identify any missed injury cases, coupled with our verification bias assessment suggest that missed injuries were extremely rare.

DISCUSSION

The NEXUS Head CT validation database provides high-quality prospective data on the epidemiology, presentations, and injury patterns associated with blunt head trauma, including injury in the elderly.[7] Our results confirm that elderly patients are at increased risk of serious injuries.[14] Although they accounted for less than one-third of enrolled patients, they sustained over 40% of all injuries, including injuries that required intervention. Furthermore, these injuries were predominantly caused by low-energy mechanisms with ground-level falls accounting for approximately two-thirds of all injuries and over half of the elderly injuries that required intervention.

Senescent changes to the brain likely explain many of our findings. Bridging veins that cross from the cerebral cortex to the dural sinus may be subject to increased tension and rupture as age-related atrophy allows the cerebral cortex to shift within the calvarium during traumatic injuries.[15,16] The fragile veins are vulnerable to low-energy trauma, such as impacts from ground-level falls, and subsequent hemorrhage will predominantly occur into the subarachnoid and subdural spaces.[15,16] We found that subdural and subarachnoid hemorrhage were present in over half of the patients who sustained intracranial injuries and two-thirds of patients who died of their injuries.

It is important to note that the initial bleeding from these injuries will merely displace the cerebrospinal fluid and may not be associated with detectable brain injury. This is consistent with our finding that approximately 1 in every 6 elderly patients with intracranial injuries lacked historical or physical evidence of serious injury. Clinical judgment is unreliable in identifying elderly patients who harbor serious injuries, and CT head imaging provides the only definitive means of identifying early injuries in many patients.[17-22] Our findings are also consistent with well-validated clinical decision rules for CT head imaging of blunt trauma patients that consistently find that older age is an independent predictor of serious intracranial injury and excludes older patients from low-risk classification.[7,9,21,22] The routine use of CT imaging is further bolstered by the fact that the risk of imaging (lethal radiation-induced malignant transformation) is significantly lower among older individuals due to their decreased life expectancy.[23-25]

Frailty and senescent changes likely explain the poor outcomes we observed for patients who required neurosurgical intervention for their injuries. Two-fifths of these patients died from their injuries, and an additional two-fifths required prolonged care to support their recovery. Only a small minority, less than 1 in 6 patients, were able to recover sufficiently to enable them to return home. We found that 55 of the 130 (42.3%) patients who required an intervention for their subdural hematoma died. This contrasts with death rates near 30% for neurosurgical intervention for subdural hematomas among the general population.[26] Specific information on outcomes is important in informing care decisions for elderly patients, and poor outcomes associated with intervention may be particularly informative in making decisions in patients who have significant premorbid infirmity.[27]

It is worth noting that our data clearly show that the clinical detection of skull fractures is limited. We specifically required clinicians to assess patients for evidence of skull fracture, and despite their vigilance, physicians were unable to detect signs of skull fracture in over two-thirds of the patients who ultimately sustained such injuries. This is particularly important for practitioners who may rely on evidence of skull fracture to make imaging and care decisions.

Questions that are not addressed in this study include the optimal timing of imaging for neurologically intact individuals. Immediate imaging on presentation offers the advantage of early identification of injuries that require intervention but may miss or underestimate the significance of small subdural hematomas that can later become problematic. In contrast, delayed imaging would likely identify most serious injuries, particularly those that require early intervention, but could delay identification of some injuries that require emergent intervention. Our study is also limited in determining which patients require reimaging, either due to abnormalities on their initial CT or extenuating circumstances, such as the use of anticoagulants. Although we did not specifically explore the importance of anticoagulation in elderly patients, our prior work has documented an increase in the risk and severity of intracranial injuries related to anticoagulation.[28] However, the risk of delayed hemorrhage appears to be low among elderly blunt head trauma patients who have normal initial CT imaging, regardless of their anticoagulant use.[29]

Finally, we found a low rate of spine injuries among older patients who sustained blunt head trauma but noted increasing prevalence with increasing severity of head injury, which is likely related to the severity of mechanism. The NEXUS c-spine decision tool exhibited high sensitivity in identifying injuries requiring intervention, with misclassification only occurring in patients with extreme advanced age, those with spine injuries of indeterminate age, and those with higher energy mechanisms. In this regard, the NEXUS tool likely provides adequate evaluation for most elderly blunt trauma patients.[11,30,31] On the other hand, the risk of cervical spine imaging in the elderly is minimal and is well below the threshold used in formulating the NEXUS rule.[32] Cautious clinicians who feel compelled to identify all spine injuries, including injuries that require no intervention, should obtain CT spine imaging in conjunction with CT head imaging.

In conclusion, older patients are at high risk of sustaining serious intracranial injuries even with low-risk mechanisms of injury like ground-level falls. Clinical evaluation is unreliable and frequently fails to identify patients with significant injuries, making routine CT head imaging the cornerstone of injury detection. Outcomes, particularly after intervention, can be poor, likely reflecting premorbid senescent impairments and prolonged or incomplete recovery from injuries.

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