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Trauma center transfer of elderly patients with mild Traumatic Brain Injury improves outcomes

Ana M. Velez [a, *], Spiros G. Frangos [b], Charles J. DiMaggio [b, c], Cherisse D. Berry [b], Jacob B. Avraham [a], Marko Bukur [b]

[a] New York University School of Medicine, Department of Surgery, 462 First Avenue, NBV 15 N1, 10016, New York, NY, USA
[b] New York University School of Medicine, Department of Surgery, Division of Trauma and Acute Care Surgery, 462 First Avenue, NBV 15 N1, 10016, New York, NY, USA
[c] New York University School of Medicine, Department of Population Health, New York, NY, USA

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ABSTRACT

Background: Elderly patients with Traumatic Brain Injury (TBI) are frequently transferred to designated Trauma Centers (TC). We hypothesized that TC transfer is associated with improved outcomes.
Methods: Retrospective study utilizing the National Trauma Databank. Demographics, injury and outcomes data were abstracted. Patients were dichotomized by transfer to a designated level I/II TC vs. not. Multivariate regression was used to derive the adjusted primary outcome, mortality, and secondary outcomes, complications and discharge disposition.
Results: 19,664 patients were included, with a mean age of 78.1 years. 70% were transferred to a level I/II TC. Transferred patients had a higher ISS (12 vs. 10, $p < 0.001$). Mortality was significantly lower in patients transferred to level I/II TCs (5.6% vs. 6.2%, Adjusted Odds Ratio (AOR) 0.84, $p = 0.011$), as was the likelihood of discharge to skilled nursing facilities (26.4% vs. 30.2%, AOR 0.80, $p < 0.001$).
Conclusions: Elderly patients with mild TBI transferred to level I/II TCs have improved outcomes. Which patients with mild TBI require level I/II TC care should be examined prospectively.

Introduction

According to the United States Department of Health and Human Services, the elderly population (age 65 and over) reached 47.8 million in 2015, an increase of 30% since 2005, making this the fastest growing age group in the United States.[1]Trauma is the seventh leading cause of death in the elderly population,[2] and the incidence of trauma in this demographic will continue to rise with the growth of this age group. Traumatic brain injury (TBI) is a leading cause of death among trauma patients, accounting for one third of all trauma mortalities.[3] The rate of TBI associated emergency department visits in older adults has risen from 373.1 per 100,000 to 603.3 per 100,000 over a 10 year period. The vast majority of these injuries are attributed to falls, followed by motor vehicle accidents, pedestrians struck and other causes.[4]

Studies have shown that the elderly population has the highest incidence of TBI associated hospitalization and mortality compared to all other age groups. This difference in outcomes compared to younger patients may be attributed, in part, to underlying comorbid conditions and decreased physical reserve in elderly patients.[5] Additionally, normal physiologic changes in the aging brain, such as atrophy of the brain parenchyma and decreased neuronal plasticity result in increased susceptibility to cellular loss, intracerebral vascular injury and diminished cerebral perfusion, all of which may contribute to poor neurologic and overall recovery from trauma.[6] Furthermore, elderly patients with TBI have worse functional outcomes, with physical, cognitive and psychological disabilities developing post-injury.[7]

The management of patients with mild TBI has been the subject of active debate. Treatment guidelines for patients with moderate or severe intracranial injuries are established and are frequently applied to patient with mild TBI as consensus is lacking on the ideal management of these patients.[8] This ultimately has led to the

* Corresponding author. New York University School of Medicine, Department of Surgery, 462 First Avenue, NBV 15 N1, New York, NY, 10016, USA.
E-mail addresses: veleza04@nyumc.org (A.M. Velez), spiros.frangos@nyumc.org (S.G. Frangos), charles.dimaggio@nyumc.org (C.J. DiMaggio), cherisse.berry@nyumc.org (C.D. Berry), jacob.avraham@nyumc.org (J.B. Avraham), marko.bukur@nyumc.org (M. Bukur).

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transfer of patients with mild TBI to higher level trauma centers for neurosurgical evaluation and interval head imaging. The utility of such measures remains unclear in patients with mild intracranial injuries.[9] Recently, Joseph et al. developed brain injury guidelines (BIG) in an attempt to identify patients with intracranial injury that may be managed primarily by acute care physicians.[10–13] While their findings suggest that a select group of patients with mild TBI may not warrant neurosurgical evaluation, obviating the need to transfer or even admit some of these patients, this experience has yet to be validated at a national level. Given the increased risk of death and complications in elderly patients with TBI,[14,15] this population may warrant special consideration in order to optimize outcomes.

In the present study, we performed a retrospective review of treatment patterns in elderly patients with mild TBI and examined outcomes using the National Trauma Databank (NTDB). We hypothesized that the transfer of elderly patients to designated trauma centers would have a favorable impact on outcomes.

Materials and methods

This was a retrospective study utilizing the National Trauma Databank 2015 research data set. We examined elderly patients with isolated blunt TBI (Head Abbreviated Injury Score (AIS) ≥ 3, all other body region AIS ≤ 2). Patients were abstracted from the NTDB if they were 65 years of age or older and had an International Classification of Disease—9 code compatible with a diagnosis of traumatic intracranial injury on admission computed tomography (CT) of the head. Patients were excluded from the analysis if they died in the emergency department or had non-survivable injuries (Injury Severity Score [ISS] = 75 or Head AIS = 6).

Various patient demographic characteristics were collected from the NTDB including age, gender, ethnicity, Charlson Comorbidity Index, and primary insurance status. Physiologic and injury characteristics were also obtained and included admission systolic blood pressure (SBP), Glasgow coma scale (GCS) score, Head AIS, ISS, mechanism of injury and type of TBI sustained. Hospital characteristics evaluated included type of trauma center designation as well as neurosurgical availability. Patients were stratified into two groups for analysis based on transfer status. Those who were initially evaluated at and admitted to a non-verified or level III/IV trauma center versus those transferred from one hospital's emergency department to a level I/II trauma center for treatment.

The primary outcome of interest was all-cause mortality, which was defined as in-hospital deaths as well as patients referred to hospice. The secondary outcomes examined were complications and discharge disposition. No patients required neurosurgical intervention (i.e. craniotomy or intra-cranial pressure monitor) so these outcomes were not analyzed. Means were compare for continuous data that were normally distributed using the independent sample *t*-test, while medians were compared for non-parametric data using the Mann-Whitney U or Kruskal Wallis test. Categorical variables were analyzed using chi-square analysis. For the purpose of our analysis, a two-tailed p-value of <0.05 was considered statistically significant. Multivariate logistic regression models where created to adjust for the effect of trauma center transfer for each outcome of interest and to derive adjusted *p*-values and odds ratios (AOR). All statistical analysis was done using the Statistical Package for the Social Sciences (SPSS; IBM, Armonk, NY) Statistics Version 22.

Results

A total of 19,664 elderly patients with mild TBI met inclusion

Table 1
Demographic and injury characteristics of study population.

Characteristics	Total (N = 19,664)	Level I/II TC (N = 13,754)	Lower tier/Nonverified (N = 5910)	*p*-value
Age (years, Mean ± SD)	78.1 ± 6.9	78.1 ± 6.9	78.0 ± 7.0	0.685
Males (%)	47.8	47.8	47.9	0.974
Ethnicity (%)				
Caucasian	87.7	88.2	86.4	0.001
Other	6.4	6.0	7.3	0.001
African American	4.2	4.2	4.4	0.428
Asian	1.8	1.7	1.9	0.325
Insurance Status (%)				
Private	14.6	13.9	16.2	<0.001
Medicare	80.2	80.6	79.4	0.070
Medicaid	1.2	1.2	1.4	0.372
Uninsured	3.9	4.3	3.0	<0.001
Charlson Score Median [IQR]	4[3,6]	4[3,6]	4[3,5]	<0.001
SBP (mmHg, Mean ± SD)	148.8 ± 29.7	148.2 ± 29.2	150.2 ± 30.9	<0.001
Admission GCS Median [IQR]	15[15]	15[15]	15[15]	0.532
Head AIS Median [IQR]	4[4]	4[4]	4[4]	0.616
ISS Median [IQR]	11[9,17]	12[9,17]	10[9,17]	<0.001
Mechanism of injury (%)				
Falls	92.5	93.0	91.5	<0.001
Motor Vehicle Accidents	6.7	6.4	7.5	0.003
Cyclist Struck	0.4	0.5	0.5	0.070
Pedestrian Struck	0.4	0.1	0.5	<0.001
Pattern of head injury (%)				
Contusion	7.9	8.0	7.5	0.226
Concussion	3.4	3.3	3.5	0.578
Skull fracture	12.0	12.1	11.9	0.737
SAH	36.9	37.1	36.5	0.430
SDH	58.8	59.7	56.8	<0.001
EDH	1.8	1.9	1.7	0.225
Other	20.2	20.2	20.1	0.891
Multiple Injuries (≥2)	29.7	30.6	27.5	<0.001

SD = standard deviation; IQR = interquartile range; SBP = systolic blood pressure; GCS = Glasgow coma scale; AIS = abbreviated injury scale; ISS = injury severity score; SAH = subarachnoid hemorrhage; SDH = subdural hemorrhage; EDH = epidural hemorrhage.

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Table 2
Hospital characteristics.

Characteristics	Total (N = 19,664)	Level I/II TC (N = 13,754)	Lower tier/Nonverified (N = 5910)	*p*-value
Trauma Center Designation (%)				
Level I	49.7	71.0	0.0	<0.001
Level II	20.3	29.0	0.0	
Level III	10.3	0.0	34.4	
Level IV	0.2	0.0	0.4	
Nonverified	19.5	0.0	65.2	
Number of Neurosurgeons (%)				
None	1.3	0.0	4.2	<0.001
1–2	8.5	5.4	15.6	
3–5	47.6	46.3	50.8	
>6	42.7	48.3	29.5	

criteria. 70% of patients (13,754) were transferred to a level I/II trauma center, with the remainder being treated at non-designated or lower tier centers. Demographic, physiologic and injury characteristics of the study population are summarized in Table 1. Falls accounted for the vast majority of injuries (92.5%) and were more frequent in patients transferred to level I/II trauma centers (93% vs 91.5%, $p < 0.001$) while motor vehicle accidents were more common in patients that were not transferred (6.4 vs. 7.5%, $p = 0.003$). Subdural Hemorrhage (SDH) was by far the most frequent TBI pattern encountered (58.8%). In patients transferred to trauma centers, a greater proportion had incurred SDH (59.7% vs. 56.8%, $p < 0.001$) and had sustained multiple patterns of intracranial injury (2 or more types, 30.6% vs. 27.5%, $p < 0.001$). Other types of TBI were equally dispersed between transferred and non-transferred groups.

With regard to hospital characteristics (Table 2), patients were most frequently transferred to level I trauma centers (71% vs. 29% level II) and most commonly from non-designated (65.2%) or level III trauma centers (34.4%). The majority (80.3%) of initial treating centers had neurosurgical coverage with 3 or more neurosurgeons available, while only 4.2% had no neurosurgical coverage available.

When examining our primary outcomes (Table 3), elderly patients with minor TBI showed a trend toward decreased all-cause mortality when transferred to a level I/II trauma center, as opposed to those patients that were not transferred (5.6% vs 6.2%, p value = 0.125). After adjusting for age, race, insurance status, Charlson score, mechanism of injury, ISS, and type of TBI, transfer to a level I/II trauma center was associated with a 16% reduction in all-cause mortality [Adjusted Odds Ratio (AOR) 0.84, 95% Confidence Interval (CI) 0.73–0.96, adjusted p value = 0.011]. Other factors associated with an increased risk of death in elderly patients with mild TBI were increasing age (3% increased risk/year, 95% CI 1.02–1.04, adjusted p value < 0.001), Charlson Score (AOR 1.21, 95% CI 1.18–1.25, adjusted p value < 0.001), as well as suffering any post-injury complication (AOR 5.92, 95% CI 5.12–6.84).

Individual types of TBI were also examined (Table 4) to determine which injury patterns would most benefit from trauma center transfer. Intraparenchymal contusions (AOR 0.65, 95% CI 0.43–0.98, adjusted p value = 0.040), skull fractures (AOR 0.54, 95% CI 0.38–0.76, adjusted p value = 0.001), SDH (AOR 0.84, 95% CI 0.71–0.99, adjusted p value = 0.040), and patients with multiple injury patterns (AOR 0.73, 95% CI 0.59–0.90, adjusted p value = 0.003) had the greatest risk reduction in all-cause mortality when transferred to level I/II trauma centers, while other patterns of injury had no discernible benefit from transfer.

Table 3
Factors associated with mortality.

Factors	AOR	95% CI	Adjusted p value
Trauma Center Transfer	0.84	0.73–0.96	0.011
Age	1.03	1.02–1.04	<0.001
Charlson Score	1.21	1.18–1.25	<0.001
Any Complications	5.92	5.12–6.84	<0.001

Table 4
Adjusted mortality for trauma center transfers by TBI type.

TBI Pattern	AOR	95% CI	Adjusted *p* value
EDH	0.52	0.22–1.27	0.152
Skull Fracture	0.54	0.38–0.76	0.001
Concussion	0.61	0.22–1.68	0.342
Contusion	0.65	0.43–0.98	0.040
SAH	0.81	0.65–1.02	0.072
SDH	0.84	0.71–0.99	0.040
Other	0.86	0.67–1.10	0.220
Multiple Injuries	0.73	0.59–0.90	0.003

EDH = epidural hemorrhage; SAH = subarachnoid hemorrhage; SDH = subdural hemorrhage.

Table 5
Adjusted discharge disposition for trauma center transfers.

Discharge Disposition	AOR	95% CI	Adjusted *p* value
Home	1.14	1.06–1.21	<0.001
Rehabilitation facility	1.08	0.98–1.19	0.090
LTAC/SNF	0.80	0.75–0.86	<0.001

LTAC = long term acute care; SNF = skilled nursing facility.

With regard to our secondary outcomes (Table 5), transfer to a trauma center was found to have a measurable impact on discharge disposition. Patients treated at level I/II trauma centers after TBI were 14% more likely to be discharged home (AOR 1.14, 95% CI 1.06–1.21, adjusted p value < 0.001)) and were discharged to long-term acute care (LTAC) or skilled nursing facilities (SNFs) 20% less frequently (AOR 0.80, 95% CI 0.75–0.86, adjusted p value < 0.001). Though overall there was a trend towards higher complications in patients treated at level I/II centers (Table 6, 7.7% vs. 6.9%, $p = 0.058$), after adjusting for variances in patient characteristics there was no significant difference in the adjusted rate of complications (AOR 1.12, 95% CI 0.99–1.27, adjusted p value = 0.060).

Discussion

As the population continues to age and older adults remain more active, the rate of TBIs sustained by elderly patients will rise, as will the number elderly trauma patients encountered in hospitals nationwide. As individuals age, both physiologic changes and pathologic conditions make patients more susceptible to even minor injury.[5,6] There is abundant evidence documenting the increased risk of death and complications in the elderly trauma patient.[14–17]

Table 6
Unadjusted outcomes of study population.

Characteristics	Total (N = 19,664)	Level I/II TC (N = 13,754)	Lower tier/Nonverified (N = 5910)	*p*-value
Mortality (%)	5.8	5.6	6.2	0.125
Any Complication (%)	7.4	7.7	6.9	0.058
Discharge Disposition (%)				
Home	51.1	51.6	50.1	0.046
Rehabilitation facility	13.5	13.9	12.6	0.011
LTAC/SNF	27.5	26.4	30.2	<0.001
Hospice	2.1	2.0	2.3	0.141
Discharge from ED	2.0	2.4	0.9	<0.001
Other	0.1	0.3	0.0	<0.001

LTAC = long term acute care; SNF = skilled nursing facility; ED = emergency department.

Studies have demonstrated that organized trauma systems result in improvement of patient outcomes.[18,19] These findings are reflected in the current guidelines from the American College of Surgeons (ACS) Committee on Trauma, developed to assist in the identification of patients that should be considered for transfer to level I and II trauma centers.[8] The appropriate triage of trauma patients involves achieving a balance between decreasing the time from injury to appropriate care and optimizing use of resources at trauma centers.[20] Nationally, more than a third of severely injured patients are admitted to non-designated trauma centers, a triage pattern that has notable implications on patient outcomes and that makes proper secondary triage vital to effective and efficient trauma system function.[21] The injured elderly patient with TBI presents a unique treatment challenge given the range of underlying physiologic and pathologic derangements in this patient population.[5,6] Prior investigations have demonstrated poor outcomes in elderly TBI patients, even after mild injuries.[14,15,22] While improved outcomes have been shown when patients with severe TBI are treated in level I trauma centers,[23] no study has focused on the impact of treating elderly patients with mild TBI at designated trauma centers.

We found that in a large cohort of elderly patients with mild TBI, transfer to designated level I and II trauma centers is associated with a reduction in mortality and more favorable discharge placement when compared with those who received treatment at lower tier and non-designated centers. This difference in both mortality and discharge disposition was noted in spite of neurosurgical availability in 95.8% of transferring centers. While overall patient characteristics between the two groups were similar, we were able to identify injury characteristics associated with improvement in outcomes following trauma center transfer. Patients with SDH, skull fractures, intraparenchymal hemorrhages and those with two or more patterns of injury had significant reduction in mortality with transfer. Identifying injury patterns associated with poor outcomes is a key factor in the selection of patients who would benefit from higher levels of care. While the BIG classification proposed by Joseph et al. aims at standardizing the treatment of patients with TBI without the need for neurosurgical consultation and repeat cranial imaging,[10–13] recent studies have suggested these guidelines can aid in the triage of patients with mild TBI by providing a framework for risk stratification,[24,25]. Our data suggests that patients with less severe injury patterns may not benefit from transfer. Application of the BIG criteria along with consideration of patient risk factors, such as injury patterns, may help stratify patients for whom transfer is under consideration.

Accomplishing trauma center designation is a resource intensive process that permits centers to demonstrate their commitment to establishing and maintaining a higher performance status in the care of injured patients.[19,26] This has translated to improved outcomes after injury, which has been demonstrated in multiple prior investigations.[18,19,23,26] In a study by DuBose et al. assessing the association between outcomes in patients with isolated severe TBI (head AIS $\geq$ 3) and ACS level designation using NTDB data, the authors found that patients treated at level II centers had increased mortality, complications and progression of neurologic insult compared to patients treated at level I trauma centers.[23] Importantly, along with ACS designation, this study identified age $\geq$55 as an independent risk factor for increased mortality in TBI patients (AOR 2.53, $p < 0.001$).

It is clear that TBI in patients of advanced age is associated not only with an increased mortality risk, but also with poor functional outcomes. Functional impairment after mild TBI has largely been under appreciated, however studies have shown that mild TBI can result in chronic cognitive and psychosocial impairment[27–29] Brown et al. found that in patients with severe TBI, treatment at a level I center was associated with a 16% improvement in functional independence and 10% improvement in independent expression, compared to patients treated at level II centers.[27] This study also found age to be an important factor, with age <55 being independently associated with improved functional independence. In the TRACK-TBI study which evaluated early cognitive outcomes in patients with mild TBI, older age was associated with an increased risk of poor cognitive performance at 3 months post injury.[28] Similarly, the UPFRONT study which assessed variables predictive of outcome in patients with mild TBI found that older age was strongly predictive of poor functional outcomes, assessed by Glasgow Outcome Scale Extended score.[29]

Although we have demonstrated an associated decrease in mortality for patients treated at level I and II centers, the reasons behind this potential difference are not entirely clear and may be interrelated to some of the factors previously mentioned. We found that 70% of the patients in this cohort were transferred to level I and II centers. Prior studies have demonstrated a correlation between improved outcomes and volume in the trauma population.[30] A study evaluating geriatric trauma patients in Pennsylvania found that larger geriatric volumes were associated with lower mortality and complications.[31] Additionally, level I and II trauma centers have more resources compared to lower designation centers and are frequently associated with an academic institution. This may allow trauma care providers to engage the expertise of multidisciplinary teams, including neurosurgeons, neurologists, geriatricians, and rehabilitation specialists. Previous investigations have shown beneficial outcomes in elderly trauma patients after routine consultation of geriatric specialists.[32]

The findings of this investigation must be taken with consideration to its retrospective nature. There may be confounding factors that were not captured in our research design or though the NTDB data set. As the NTDB is a convenience sample of information voluntarily reported primarily by level I and II trauma centers, it has inherent issues related to the quality of data reported, as well as the variables and detail of data available. These factors can lead to selection bias, which could result in the data favoring level I and II

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centers. Additionally, as the majority of the reported data is derived from level I and II centers, reporting bias may be an important factor to take into account as these centers are likely to be more attentive in both the capture and reporting of data than non-designated centers. Despite the potential for bias in the NTDB, the actual beneficial differences observed in our study may in fact be greater, as the centers that submit to the NTDB have some commitment to trauma care that other institutions evaluating and treating TBI without NTDB reporting of outcomes do not. Nonetheless, the observed effect differences must include consideration of the large sample size of our analysis as this may permit statistical significance to be reached in spite of relatively small clinical differences. Additionally, there are variables that could not be evaluated in the NTDB data set, such as changes in neurologic status during the course of hospitalization and discharge Glasgow outcome score, which would allow us to analyze functional outcomes. Other interventions such as transfusion of plasma or platelets or drug specific reversal agents for patients on anticoagulant/anti-platelet medications were also not available. Finally, given the implications of the BIG protocol on possible changes in the management of patients with TBI, it would have been advantageous to recreate the BIG criteria for our analysis. However, data on the size and location of intracranial hemorrhages, as well as preexisting anticoagulation status could not be obtained through the NTDB data set.

Conclusion

Our findings suggest that in the elderly population with mild TBI, transfer to level I or II trauma centers rather than treatment at lower tier or non-designated centers, leads to improved outcomes. In this NTDB convenience sample, transfer to designated trauma centers is associated with decreased all-cause mortality and favorable discharge placement. Identifying TBI patients that benefit from trauma transfer may optimize both patient outcomes and resource utilization and should be examined prospectively.

Conflicts of interest

The authors have no conflict of interest to report. This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

References

1. United States Department of Health and Human Services. Profile of older Americans. Available at: https://www.giaging.org/documents/A_Profile_of_Older_Americans__2016.pdf; 2016. Accessed February 20, 2018.
2. Centers for Disease Control and Prevention. Ten leading causes of death by age group, United States-2015. Available at: https://www.cdc.gov/injury/wisqars/pdf/leading_causes_of_death_by_age_group_2015-a.pdf; 2015. Accessed February 20, 2018.
3. Taylor CA, Bell JM, Breiding MJ, Xu L. Traumatic brain injury—related emergency department visits, hospitalizations, and deaths — United States, 2007 and 2013. *MMWR Surveill Summ*. 2017;66(No. SS-9):1—16.
4. Center for Disease Control and Prevention. Injury prevention and control: rates of TBI related emergency department visits by age group -United States, 2001—2010. Available at: https://www.cdc.gov/traumaticbraininjury/data/rates_ed_byage.html. Accessed February 20, 2018.
5. Calland JF, Ingraham AM, Martin N, Marshall GT, Schulman CI, et al. Evaluation and management of geriatric trauma: an Eastern Association for the Surgery of Trauma practice management guideline. *J Trauma Acute Care Surg*. 2012;73:S345—S350.
6. Wilberger J, Jho D. Geriatric neurotrauma. In: Yelon J, Luchette F, eds. *Geriatric Trauma and Critical Care*. NY: Springer; 2014.
7. LeBlanc J, de Guise E, Gosselin N, Feyz M. Comparison of functional outcome following acute care in young, middle-aged and elderly patients with traumatic brain injury. *Brain Inj*. 2006;20:779—790.
8. American College of surgeons committee on trauma. In: Rotondo MFCC, Smith RS, eds. *Resources for the Optimal Care of the Injured Patient*. Chicago, IL: American College of Surgeons; 2014:30—34.
9. Carney N, Totten AM, O'Reilly C, Ullman JS, Hawryluk GW, et al. Guidelines for the management of severe traumatic brain injury, fourth edition. *Neurosurgery*. 2017;80:6—15.
10. Joseph B, Aziz H, Sadoun M, Kulvatunyou N, Tang A, et al. The acute care surgery model: managing traumatic brain injury without an inpatient neurosurgical consultation. *J Trauma Acute Care Surg*. 2013;75:102—105.
11. Joseph B, Aziz H, Pandit V, Kulvatunyou N, Sadoun M, et al. Prospective validation of the brain injury guidelines: managing traumatic brain injury without neurosurgical consultation. *J Trauma Acute Care Surg*. 2014;77:984—988.
12. Joseph B, Friese RS, Sadoun M, Aziz H, Kulvatunyou N, et al. The BIG (brain injury guidelines) project: defining the management of traumatic brain injury by acute care surgeons. *J Trauma Acute Care Surg*. 2014;76:965—969.
13. Joseph B, Pandit V, Haider AA, Kulvatunyou N, Zangbar B, et al. Improving hospital quality and costs in nonoperative traumatic brain injury: the role of acute care surgeons. *JAMA Surg*. 2015;150:866—872.
14. Hukkelhoven CW, Steyerberg EW, Rampen AJ, Farace E, Habbema JD, et al. Patient age and outcome following severe traumatic brain injury: an analysis of 5600 patients. *J Neurosurg*. 2003;99:666—673.
15. Thompson HJ, McCormick WC, Kagan SH. Traumatic brain injury in older adults: epidemiology, outcomes, and future implications. *J Am Geriatr Soc*. 2006;54:1590—1595.
16. Jacobs B, Beems T, Stulemeijer M, van Vugt AB, van der Vliet TM, et al. Outcome prediction in mild traumatic brain injury: age and clinical variables are stronger predictors than CT abnormalities. *J Neurotrauma*. 2010;27:655—668.
17. McIntyre A, Mehta S, Aubut J, Dijkers M, Teasell RW. Mortality among older adults after a traumatic brain injury: a meta-analysis. *Brain Inj*. 2013;27:31—40.
18. MacKenzie EJ, Rivara FP, Jurkovich GJ, Nathens AB, Frey KP, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354:366—378.
19. Demetriades D, Martin M, Salim A, Rhee P, Brown C, et al. The effect of trauma center designation and trauma volume on outcome in specific severe injuries. Ann Surg:242:512-517.
20. Nathens AB, Jurkovich GJ, MacKenzie EJ, Rivara FP. A resource-based assessment of trauma care in the United States. *J Trauma*. 2004;56:173—178.
21. Harrington DT, Connolly M, Biffl WL, Majercik SD, Cioffi WG. Transfer times to definitive care facilities are too long: a consequence of an immature trauma system. *Ann Surg*. 2005;241:961—966. discussion 966-968.
22. Kinsella GJ, Olver J, Ong B, Gruen R, Hammersley E. Mild traumatic brain injury in older adults: early cognitive outcome. *J Int Neuropsychol Soc*. 2014;20:663—671.
23. DuBose JJ, Browder T, Inaba K, Teixeira PG, Chan LS, et al. Effect of trauma center designation on outcome in patients with severe traumatic brain injury. *Arch Surg*. 2008;143:1213—1217.
24. Capron GK, Voights MB, Moore HR, Wall DB. Not every trauma patient with a radiographic head injury requires transfer for neurosurgical evaluation: application of the brain injury guidelines to patients transferred to a level 1 trauma center. *Am J Surg*. 2017;214:1182—1185.
25. Martin GE, Carroll CP, Plummer ZJ, Millar DA, Pritts TA, et al. Safety and efficacy of brain injury guidelines at a Level III trauma center. *J Trauma Acute Care Surg*. 2018;84:483—489.
26. Biffl WL, Harrington DT, Majercik SD, Starring J, Cioffi WG. The evolution of trauma care at a level I trauma center. *J Am Coll Surg*. 2005;200:922—929.
27. Brown JB, Stassen NA, Cheng JD, Sangosanya AT, Bankey PE, et al. Trauma center designation correlates with functional independence after severe but not moderate traumatic brain injury. *J Trauma*. 2010;69:263—269.
28. McMahon P, Hricik A, Yue JK, Puccio AM, Inoue T, et al. Symptomatology and functional outcome in mild traumatic brain injury: results from the prospective TRACK-TBI study. *J Neurotrauma*. 2014;31:26—33.
29. van der Naalt J, Timmerman ME, de Koning ME, van der Horn HJ, Scheenen ME, et al. Early predictors of outcome after mild traumatic brain injury (UPFRONT): an observational cohort study. *Lancet Neurol*. 2017;16:532—540.
30. Marx WH, Simon R, O'Neill P, Shapiro MJ, Cooper AC, et al. The relationship between annual hospital volume of trauma patients and in-hospital mortality in New York State. *J Trauma*. 2011;71:339—345.
31. Matsushima K, Schaefer EW, Won EJ, Armen SB, Indeck MC,et al. Positive and negative volume-outcome relationships in the geriatric trauma population. JAMA Surg2014:149:319-326.
32. Bradburn E, Rogers FB, Krasne M, Rogers A, Horst MA, et al. High-risk geriatric protocol: improving mortality in the elderly. *J Trauma Acute Care Surg*. 2012;73:435—440.