Published in final edited form as:

Am Surg. 2012 December ; 78(12): 1369–1375.

Mortality Factors in Geriatric Blunt Trauma Patients: Creation of a Highly Predictive Statistical Model for Mortality Using 50,765 Consecutive Elderly Trauma Admissions from the National Sample Project

TJASA HRANJEC, M.D., M.S., ROBERT G. SAWYER, M.D., JEFFREY S. YOUNG, M.D., BRIAN R. SWENSON, M.D., M.S., and JAMES F. CALLAND, M.D.

Department of Surgery, University of Virginia, Charlottesville, Virginia

Abstract

Elderly patients are at high risk for mortality after injury. We hypothesized that trauma benchmarking efforts would benefit from development of a geriatric-specific model for risk-adjusted analyses of trauma center outcomes. A total of 57,973 records of elderly patients (age older than 65 years), which met our selection criteria, were submitted to the National Trauma Database and included within the National Sample Project between 2003 and 2006. These cases were used to construct a multivariable logistic regression model, which was compared with the American College of Surgeons Committee on Trauma's Trauma Quality Improvement Project's (TQIP) existing model. Additional spline regression analyses were performed to further objectively quantify the physiologic differences between geriatric patients and their younger counterparts. The geriatric-specific and TQIP mortality models shared several covariates: age, Injury Severity Score, motor component of the Glasgow Coma Scale, and systolic blood pressure. Our model additionally used temperature and the presence of mechanical ventilation. Our geriatric-specific regression model generated a superior c-statistic as compared with the TQIP approximation (0.85 vs 0.77; $P = 0.048$). Spline analyses demonstrated that elderly patients appear to be less likely to tolerate relative hypotension with higher observed mortality at initial systolic blood pressures of 90 to 130 mmHg. Although the TQIP model includes a single age component, these data suggest that each variable needs to be adjusted for age to more accurately predict mortality in the elderly. Clearly, a separate geriatric model for predicting outcomes is not only warranted, but necessary.

Although injury has been long considered the leading cause of death in younger and middle-aged adults, elderly patients have been recently identified as having some of the highest injury-related mortality rates.^{1, 2} Elderly patients with blunt injuries consume more than one-third of all healthcare resources expended on trauma care and have higher in-hospital mortality than do their younger counterparts.¹ As the American population ages, a significant percentage of patients entering trauma centers will be in the geriatric age range.

The higher observed mortality in the elderly has been attributed to several factors including reduced cardiopulmonary reserve, poor nutritional status, propensity for bleeding after fractures, etc.³ Additionally, several risk factors have emerged in the literature that highlight the complications often seen among geriatric trauma patients, including pneumonia, adult

Address correspondence and reprint requests to James F. Calland, M.D., Box 800709, Department of Surgery, University of Virginia School of Medicine, Charlottesville, VA 22908. jfc3t@virginia.edu.

Presented from the Podium at the Annual Meeting of The American Association for the Surgery of Trauma, Boston, Massachusetts, September 24, 2011.

respiratory distress syndrome, sepsis, cardiac failure, and multi-system organ failure.³ Although there are obvious physiological changes with age, there is no accurate model that has emerged to quantify the risk of death and complications after injury in the geriatric population.⁴

The Trauma Quality Improvement Program (TQIP),^{5, 6} designed by the American College of Surgeons (ACS) Committee on Trauma in 2006 and piloted in June 2008 was created to predict trauma mortality. The TQIP model is a validated, risk-adjusted, outcomes-based model created to predict mortality for all injured adult patients including the elderly. Despite its excellent ability to predict outcomes in adult patients, we hypothesized that elderly patients would benefit from a geriatric-specific model. We also postulated that geriatric trauma patients with a high probability of dying could be identified based on their physiological status at the time of their admission.

Methods

Ethics Statement

The concept of this work was reviewed by the Human Investigation Committee at the University of Virginia before investigation and deemed to be exempt from need for consent or other human considerations involved in the protection of human subjects.

Data Source

Data were extracted from the National Trauma Data Bank National Sample Program⁶ (NTDB NSP 2003–2006), which was developed and is maintained by the ACS as a public service. The National Sample Program (NSP) was intended to enhance the original NTDB through creation of a probabilistic and nationally representative sample of 100 Level I and II trauma centers from the NTDB's 900 hospitals. The program, with improved data quality, has been used for clinical outcomes research, injury surveillance, and trauma care assessment. The computerized database contains information on all trauma admissions with patient demographics (age, sex, race etc.), injury and diagnosis, injury severity, procedure codes, and outcome variables (length of stay, etc.) recorded.

Existing Model

The TQIP model⁵ is a risk-adjusted, outcomes-based measure created to improve quality of trauma care. Its purpose is to predict mortality in injured adult (16 years old or older) patients as a function of the following covariates (sorted from most to least important): initial motor Glasgow Coma Scale (GCS) score in the emergency department (ED), initial systolic blood pressure (SBP) in the ED, Injury Severity Score (ISS), age, initial pulse rate in the ED, mechanism of injury, head injury severity, abdominal injury severity, and patient transfer status. The TQIP model generates an impressive c-statistic of 0.901 across the wide spectrum of TQIP-eligible patients, from 16 to greater than 100 years of chronological age, but, like any model of physiological phenomena, would be unlikely to perform equally well across multiple strata of age. We hypothesized that by designing an elderly-specific model, we could better predict elderly outcomes after trauma admission and highlight differences in the physiological parameters between elderly and younger adult patients.

Data Collection

One hundred trauma centers (Level I and II) contributed a total of 60,665 records of elderly patients (age 65 years or older) between years 2003 and 2006. Cases meeting the following criteria were used to create and test our model: known outcome variable mortality/survival to discharge, hospital length of stay of at least 24 hours, and an ISS greater than 0 were ultimately analyzed (n = 57,973). The remaining data set contained complete information on

gender, age, and initial motor GCS. Other data fields gathered in the ED phase of care such as use of a mechanical ventilator, temperature, and SBP in the ED were found to have a much higher rate of missing data, with 50, 10, and 64 per cent missing data, respectively. The records with omitted ventilator, temperature, and SBP data were included in the analysis to minimize selection bias and allow us to more adequately predict mortality (primary goal of the article) knowing that the interpretation of the coefficients and, therefore, explanations for the cause of death would be somewhat limited. As such, a large quantity of data was missing for certain key variables; an additional analysis of patients with only complete data ($n = 11,105$) was performed.

Variable Selection/Primary Outcome

Patient demographics, in-hospital mortality, and key determinants of geriatric trauma outcomes (age, gender, ISS, motor GCS, SBP, temperature, presence of mechanical ventilation on admission to the hospital) were established *a priori* based on the TQIP model, previous research as well as presumed covariate significance. The following variables: respiratory rate, initial pulse rate in the ED, mechanism of injury, head injury severity, abdominal injury severity, or transfer status (from TQIP model) were not included because they were either not provided in the NSP data set and/or were deemed to be minor contributors to the model. A miniscule increase in the model's c-statistic was observed when such factors were added, e.g., addition of pulse rate to the model improved c-statistic by 0.001; mechanism of injury by 0.004, etc. The primary goal of the article was to create a geriatric-specific model that would accurately predict in-hospital mortality in injured elderly trauma patients while adjusting for multiple covariates.

Statistical Analysis

Descriptive analyses comparing demographic characteristics of survivors and decedents were performed using the χ^2 statistic to compare portions and single-factor analysis of variance to compare means.

A multivariable logistic regression model was generated to estimate mortality risk as a function of age, ISS, motor GCS, SBP, temperature, and the presence of mechanical ventilation. The maximum adjusted R^2 value and c-statistic were calculated to assess the proportion of variability explained by the model and assess the model's ability to discriminate between survivors and nonsurvivors, respectively. Discrimination ability was measured using the receiver operator characteristic (ROC) curve. Results generated by the logistic regression were internally validated by a bootstrapping method (40:60). For the purpose of investigating the impact of missing data, the analyses were performed twice: once on the entire data set and second only on patients with complete data. Because critical cutoffs for SBPs are often used as triggers for trauma activation, we plotted SBP *versus* odds of death for younger adult and elderly patients to further evaluate the relationship between blood pressure and mortality. We then used spline regression to adjust SBP for all the aforementioned variables (previously included in the multivariate analysis).

Values were mean $\pm$ standard error or percentage of the group of origin. All distributions were two-tailed with $\alpha = 0.05$ considered statistically significant. All statistical analyses were performed using SAS 9.1.3 (SAS Institute, Cary, NC).

Results

Baseline Demographics

Univariate Analysis—A total of 57,973 records of elderly patients from the original 60,665 within the data set met the pre-specified inclusion criteria for data analysis. Table 1

represents the distribution of patients (alive and dead) after a traumatic injury in terms of demographics and each of the risk factors. Deceased patients were more likely to be male, on mechanical ventilation at hospital admission, having lower SBP and motor GCS, but higher ISS scores.

Multivariate Analysis—A multivariate logistic regression was used to estimate the risk of death adjusted for age, ISS, gender, motor GCS, SBP, temperature, and presence of mechanical ventilation. The model demonstrated good statistical performance with a c-statistic of 0.85 with ability to adequately discriminate between survivors and decedents. It obtained a maximum adjusted R^2 value of 0.31, indicating that one-third of the observed variability in the risk of death was explained by the model. Covariates were found to be statistically significant predictors of mortality as shown in Table 2. The largest contribution to the model's predictive performance was provided by the ISS score (Wald $\chi^2 = 1766.9$) followed by mechanical ventilation on hospital admission, motor GCS score, age, SBP, gender, and temperature. All originally specified covariates were retained in the final model. A repeat analysis with complete patient data only ($n = 11,105$) showed similar results with a c-statistic of 0.89, R^2 0.40, and significance for all predictive variables except temperature ($P = 0.058$) (results not shown).

Table 3 displays odds of death and their respective 95 per cent confidence intervals for adjusted covariates that have been included in the model. Not surprisingly, as age, ISS, and temperature increase, odds of dying increase as well. For example, an 85-year-old patient experiences a 100 per cent increased for mortality as compared with a 65 year old. An ISS score greater than 25 confers a six times higher chance of mortality as compared with those with an ISS score less than 16. Curiously, female gender seems to confer a protective effect as does increased SBP, whereas low motor GCS score and presence of intubation, be it in the field (or in the ED), seems to increase the risk for mortality approximately fivefold.

According to most trauma protocols, suspicion for more extensive injuries after blunt trauma often initiates after SBP less than 90 mmHg. This trigger may not even be adequate for adult patients as seen by the graphic representation of SBP *versus* mortality rate in Figures 1 and 2, let alone for the elderly. Systolic blood pressure of 110 mmHg in the elderly almost doubles their mortality (from 5 to 10%) when compared with SBP of 130 to 150 mmHg, for example. Furthermore, after adjusting for age, gender, mechanical ventilation, motor GCS score, temperature, and ISS, the same trend, with higher SBPs, was seen in patients as compared with younger adults to decrease patient mortality.

A side-by-side comparison of the TQIP and geriatric models is seen in Figure 3. The geriatric model generates a c-statistic of 0.85, whereas our approximation of the TQIP model's c-statistic, when applied to elderly patients, is only 0.77 (one-sided $P = 0.048$). Although age, ISS, motor GCS, and initial SBP are included in the TQIP model, the following covariates, which are deemed to be highly significant contributors to mortality outcomes in the geriatric population, are not gender, temperature and (most importantly), and the presence of mechanical ventilation on hospital admission (Wald $\chi^2 = 1766.9$). When the geriatric model is applied to the adult population (age younger than 65 years), there is no statistically significant improvement in the model's performance when compared with an approximation of the standard TQIP model (data not shown).

Discussion

The impact of serious injury on the physiology of elderly patients is not adequately understood.⁷ Previous research has plainly shown that the elderly have higher mortality than younger injured patients given the same extent of injury. Even in the case of moderate

injuries that are survivable in younger adults, the elderly may die.^{8–10} Furthermore, elderly patients may receive improper and/or delayed care given the fact that the ubiquitous physiological criteria for trauma team activation often are mostly based on the physiological parameters of younger adults.^{2, 11–14}

Despite a significant body of evidence showing physiological differences between younger adults and elderly patients, clinical studies continue to combine the two groups.^{15, 16} As a result, the unique characteristics and effects of serious injuries on the elderly are diluted by the larger number of the young individuals in any of these data sets.^{7, 9} We hypothesized that by designing an elderly-specific model, we could better predict elderly outcomes after trauma admission and highlight differences in the physiological parameters between elderly and younger adult patients.

The 2008 TQIP pilot program⁵ set out to improve the quality of trauma care in the United States through risk-adjusted outcomes-based modeling of the mortality and complications of patients admitted to trauma centers. However, the geriatric population represented less than 20 per cent of the total research population included in the TQIP study. Because there is growing evidence that geriatric patients should be studied separately, not unlike the pediatric population, we have created a geriatric-specific model using the NTDB NSP data set. Mechanical ventilation on hospital admission, age, gender, initial ISS, GCS motor, SBP, and temperature were found to be significant independent predictors of mortality in the elderly with ISS and mechanical ventilation imposing the most influence on the outcome (Wald χ^2). Initial SBP, GCS motor, pulse rate, ISS, age, mechanism of injury, head and abdominal injury severity, and transfer status are critical components of the TQIP model, with ISS, SBP and GCS motor contributing the greatest magnitude of effect to the model's performance. Gender, temperature, and mechanical ventilation—critical components of the geriatric model and therefore, important predictors of geriatric outcomes—are absent from the TQIP model, likely because these parameters do not highly influence outcomes in younger adults. In addition, the difference in accuracy between the TQIP and geriatric-specific models, 77 and 85 per cent, respectively, suggests that elderly patient outcomes would be more appropriately analyzed through a geriatric-specific model. Curiously, the relative accuracy of the models, when applied to the younger adult population, is similar.

In terms of physiological parameters, our analysis suggests that existing general criteria for hypotension should be modified for the elderly population. For example, an initial SBP threshold warranting urgent intervention is nearly ubiquitously considered to be less than 90 mmHg. However, a systolic blood pressure of 60 to 90 mmHg brings about an almost 40 per cent increase in mortality for elderly patients. Our analyses demonstrate that perhaps a minimum threshold SBP below which physicians should be alarmed should be less than 130 mmHg in patients older than 65 years of age. Once again, this finding suggests that geriatric patients should be evaluated and studied as a distinct and separate trauma cohort.

There are several limitations to our study. Although our model generated a good c-statistic and a solid area under the ROC curve, there may be other important variables affecting mortality of the injured elderly patients that were not included in the model. Respiratory rate, for example, may be an important predictor of patient outcomes; however, this physiological variable is very inconsistently reported and was, therefore, excluded. Comorbidities, delays in admission to the trauma center, or availability of the multidisciplinary trauma team may further affect the outcomes of trauma patient but were not included in our model. However, because our model was shown to be a very good performer, with a good capacity to discriminate between survivors and nonsurvivors, the likelihood that any unadjusted covariates would meaningfully change the results is low. Finally, missing data have always created substantial problems when using large databases

and yet analysis of patients with complete reports yielded very similar results, further confirming this study's reports.

Geriatric trauma outcomes are significantly worse compared with those in younger adults, likely because elderly patients have a different response to injury and present with physiological findings that vary from younger patients. Following guidelines set forth by research involving all adult and elderly patients combined, trauma team activation is often delayed for the elderly, who additionally may not be aggressively treated initially. There is substantial evidence to suggest that elderly patients should be analyzed separately from their adult counterparts with outcome models created separately for each cohort. We have created a geriatric-specific model to predict mortality of elderly trauma patients and establish independent predictors of poor outcomes. We have also established certain physiological parameters that are different from younger adults and, if confirmed, may be more appropriate when evaluating geriatric patients.

Our hope is that geriatric trauma care can ultimately be improved through a more accurate understanding of the variables that most directly influence outcome.

Acknowledgments

The National Sample Project Data were used in agreement with the Committee on Trauma, American College of Surgeons, NTDB NSP 2003–2007, Chicago, IL. The content reproduced from the NTDB NSP remains the full and exclusive copyrighted property of the American College of Surgeons. The American College of Surgeons is not responsible for any claims arising from works based on the original data, text, tables, or figures.

This work was supported by the National Institutes of Health grant 5T32AI078875-02 (Principal Investigator: Robert G. Sawyer, M.D.). The funders had no role in study design, data collection and analysis, decision to publish, or preparation of the article.

References

1. Champion HR, Copes WS, Buyer D, et al. Major trauma in geriatric patients. *Am J Public Health*. 1989; 79:1278–82. [PubMed: 2764207]
2. Lehmann R, Beekley A, Casey L, et al. (2009) The impact of advanced age on trauma triage decisions and outcomes: a statewide analysis. *Am J Surg*. 2009; 197:571–4. [PubMed: 19393350]
3. Tornetta P, Mostafavi H, Riina J, et al. Morbidity and mortality in elderly trauma patients. *J Trauma*. 1999; 46:702–6. [PubMed: 10217237]
4. Clark DE, Hannan EL, Wu C. Predicting risk-adjusted mortality for trauma patients: logistic versus multilevel logistic models. *J Am Coll Surg*. 2010; 211:224–31. [PubMed: 20670860]
5. Hemmila MR, Nathens AB, Shafi S, et al. The Trauma Quality Improvement Program: pilot study and initial demonstration of feasibility. *J Trauma*. 2010; 68:253–62. [PubMed: 20154535]
6. American College of Surgeons: Committee on Trauma. [Accessed Oct. 1, 2012] 2010. Available at: www.facs.org/trauma/ntdb/nsp.html
7. Richmond TS, Kauder D, Strumpf N, Meredith T. Characteristics and outcomes of serious traumatic injury in older adults. *J Am Geriatr Soc*. 2002; 50:215–22. [PubMed: 12028201]
8. Finelli FC, Jonsson J, Champion HR, et al. A case control study for major trauma in geriatric patients. *J Trauma*. 1989; 29:541–8. [PubMed: 2724372]
9. Knudson MM, Lieberman J, Morris JA Jr, et al. Mortality factors in geriatric blunt trauma patients. *Arch Surg*. 1994; 129:448–53. [PubMed: 8154972]
10. Baker SP, Spitz WU. Age effects and autopsy evidence of disease in fatally injured drivers. *JAMA*. 1970; 214:1079–88. [PubMed: 5536250]
11. Demetriades D, Sava J, Alo K, GC, et al. Old age as a criterion for trauma team activation. *J Trauma*. 2011; 51:754–6. [PubMed: 11586171]

12. Phillips S, Rond PC, Kelly SM, Swartz PD. The failure of triage criteria to identify geriatric patients with trauma: results from the Florida Trauma Triage Study. *J Trauma*. 1996; 40:278–83. [PubMed: 8637079]
13. Scalea TM, Simon HM, Duncan AO, et al. Geriatric blunt multiple trauma: improved survival with early invasive monitoring. *J Trauma*. 1990; 30:129–34. [PubMed: 2304107]
14. Demetriades D, Karaiskakis M, Velmahos G, et al. Effect on outcome of early intensive management of geriatric trauma patients. *Br J Surg*. 2002; 89:1319–22. [PubMed: 12296905]
15. Menaker J, Scalea TM. Geriatric care in the surgical intensive care unit. *Crit Care Med*. 2010; 38:452–9.
16. Boss GR, Seegmiller JE. Age-related physiological changes and their clinical significance. *West J Med*. 1981; 135:434–40. [PubMed: 7336713]

Fig. 1. Systolic blood pressure comparison between adults and elderly. SBP of adults (solid line) versus elderly (dotted line) patients with respect to mortality rate. Optimal SBP levels appear to be higher in elderly patients.

Fig. 2. Adjusted systolic blood pressure comparison between adults and elderly. SBP of adults (dotted) versus elderly (solid) patients with respect to mortality rate after adjusting for temperature, mechanical ventilation, gender, age etc. Once again, optimal SBP levels appear to be higher in elderly blunt trauma patients.

Fig. 3. Comparison between Trauma Quality Improvement Project's (TQIP) and geriatric blunt trauma models. Comparison of ROC curves between the geriatric and TQIP models when applied to geriatric population only. Difference between the two curves is statistically significant ($p = 0.048$).

Table 1

Frequency Distribution

	Alive		Deceased		Total		P Value
	Number	%	Number	%	Number	%	
Number of patients	53,376	92.1	4,597	7.9	57,973	100	—
Age (years) *	71.1 ± 0.1	—	70.7 ± 0.4	—	—	—	0.28
Race							
Black	3,352	6.8	262	6	3,614	6.2	<0.0001
Asian	594	1.2	59	1.4	653	1.1	
White	40,302	81.7	3,701	85.1	44,003	75.9	
Hispanic	2,673	5.4	158	3.6	2,831	4.9	
Native American	69	0.1	9	0.2	78	0.1	
Other	2,358	4.8	158	3.6	2,516	4.3	
Gender (male)	22,068	41.3	2,535	55.1	24,603	42.4	<0.0001
Mechanical ventilation	2,829	5.3	1,788	38.9	4,617	8.0	<0.0001
SBP *	146.7 ± 0.2	—	140.7 ± 0.7	—	—	—	<0.0001
Temperature *	97.2 ± 0.0	—	97.6 ± 0.1	—	—	—	<0.0001
Motor GCS *	5.8 ± 0.0	—	4.3 ± 0.0	—	—	—	<0.0001
ISS *	10.2 ± 0.0	—	21.0 ± 0.2	—	—	—	<0.0001

Frequency and percentage distribution of study population characteristics compared by univariate analysis between alive and dead patients.

* Mean ± standard error.

SBP, systolic blood pressure; GCS, Glasgow Coma Scale; ISS, Injury Severity Score.

Table 2

Mortality Predictors

Analysis of Effects	Degrees of Freedom	Wald ² Test Statistic	P Value
ISS	4	1,766.9	<0.0001
Mechanical ventilation	4	937.1	<0.0001
Motor GCS	2	807.4	<0.0001
Age	2	253.8	<0.0001
SBP	6	150.1	<0.0001
Gender	1	52.4	<0.0001
Temperature	3	15.3	0.0016

Summary of mortality predictors sorted by their contribution to the model's predictive performance (Wald ²).

ISS, Injury Severity Score; GCS, Glasgow Coma Scale; SBP, systolic blood pressure.

Table 3

Adjusted Odds Ratios of Mortality Predictors

Parameters	OR	95% CI
Age (reference: 65) (years)		
>85	2	1.8–2.2
65–75	1.86	1.7–2.0
ISS (reference: < 15)		
16–19	2.39	2.2–2.6
20–24	2.01	1.7–2.3
35–29	6.33	5.7–7.0
>30	7.21	6.4–8.2
Gender (reference: male)		
Female	0.77	0.7–0.8
Motor GCS (reference: 6)		
1	4.49	4.0–5.0
2–5	2.82	2.5–3.2
Mechanical ventilation (reference: no)		
Yes	5.1	4.6–5.6
SBP (reference: 90–120)		
0–60	1.69	1.1–2.7
60–90	1.3	1.1–1.6
120–150	0.62	0.6–0.7
150–180	0.67	0.6–0.8
Temperature (reference: 97.7–101.3) (°C)		
65–97.7	1.23	1.1–1.4
>101.3	1.24	0.5–2.5

Adjusted odds of death of independent mortality predictors with their respective 95% confidence intervals (95% CIs) as generated by the logistic regression model.

OR, odds ratio; ISS, Injury Severity Score; GCS, Glasgow Coma Scale; SBP, systolic blood pressure.