Age-Related Characteristics and Outcomes for Patients With Severe Trauma: Analysis of Japan's Nationwide Trauma Registry

Mitsuaki Kojima, MD, PhD; Akira Endo, MD, PhD*; Atsushi Shiraishi, MD, PhD; Yasuhiro Otomo, MD, PhD

*Corresponding Author. E-mail: eraeaccm@tmd.ac.jp.

Study objective: Although geriatric trauma patients are becoming more common, few large-scale analyses have comprehensively evaluated geriatric-specific characteristics in trauma. This study aims to clarify the age-specific characteristics, outcomes, and predictive accuracy of current trauma scoring systems among geriatric trauma patients.

Methods: Patients with severe trauma, with an Abbreviated Injury Scale score greater than or equal to 3, and registered in the Japan Trauma Data Bank during 2004 to 2015 were retrospectively reviewed. Age-related differences were assessed for injury mechanism, injured region, anatomic and physiologic severity, and inhospital mortality. The mortality risk was evaluated with multivariate mixed-effect models adjusted for Injury Severity Score, Revised Trauma Score, year of injury, and treating facility. Age-related differences in the accuracy of the Injury Severity Score and Revised Trauma Score for predicting inhospital mortality were evaluated with an area under the receiver operating characteristic curve.

Results: We identified 127,303 patients, including 67,316 geriatric patients (52.9%) who were aged 60 years or older. The percentage of geriatric patients increased from 31.9% to 59.7% during the study period. The most frequent injury mechanism was ground-level falls (55.2%) and the most frequently injured region was the pelvis and lower extremities (43.7%). Severity-adjusted mixed-effects models revealed a marked age-dependent increase in mortality. Although the Injury Severity Score had similar predictive accuracy among all generations, the accuracy of the Revised Trauma Score decreased with increasing age.

Conclusion: The characteristics of trauma patients varied widely according to age, and mortality risk increased steadily with increasing age, despite a decrease in anatomic injury severity. The Revised Trauma Score had decreasing predictive accuracy at older ages, suggesting that an alternative measure is needed. [Ann Emerg Med. 2019;73:281-290.]

Please see page 282 for the Editor's Capsule Summary of this article.

Readers: click on the link to go directly to a survey in which you can provide **feedback** to *Annals* on this particular article.
A **podcast** for this article is available at www.annemergmed.com.

0196-0644/$-see front matter

https://doi.org/10.1016/j.annemergmed.2018.09.034

SEE EDITORIAL, P. 291.

INTRODUCTION

Background

The mechanisms and patterns of injury among elderly individuals reportedly differ from those among younger individuals.[1] For example, elderly individuals have a higher incidence of severe extremity injuries,[2] whereas younger individuals have a higher incidence of head injuries.[3] However, changes in trauma mechanisms and injury patterns according to aging have not been clarified because of the shortage of large-scale studies. Because geriatric patients have diminished physiologic reserves and inferior preinjury functional capacities relative to younger individuals, older age itself can be an independent risk factor for trauma mortality.[4] In addition to age-related physiologic changes, the presence of preexisting chronic conditions can also affect pathophysiology in geriatric trauma patients, which is associated with increased health care resource use[5] and a higher mortality rate.[6,7]

Importance

The proportion of elderly patients admitted to trauma centers is increasing in most developed countries.[4] Furthermore, persistent increases in the average life span are expected to further increase the proportion of geriatric trauma patients in many developed countries. Japan is the country with the most rapidly increasing number of aging individuals in the world, in which elderly individuals account for greater than 26% of the total population. Because Japan has experienced a corresponding increase in health care burden that can be attributed to geriatric trauma patients, analyzing age-related changes in trauma characteristics and outcomes

Editor's Capsule Summary

What is already known on this topic

In many hospitals in developed countries, older adults now constitute the majority of trauma admissions.

What question this study addressed

How does the accuracy of commonly used measures of injury severity for predicting mortality vary by age?

What this study adds to our knowledge

In this retrospective analysis of 121,000 patients in the Japan Trauma Data Bank from 2004 to 2015, the Revised Trauma Score accurately predicted mortality in younger adults but was a poor predictor in older adults.

How this is relevant to clinical practice

Procedures to evaluate the quality of trauma care for older adults that estimate expected mortality with measures of trauma severity may be inaccurate.

with the Japanese nationwide trauma registry may also provide benefit to many other developed countries.

Goals of This Investigation

The present study aimed to identify any age-related differences in injury mechanisms, anatomic injury distributions, and mortality risk among patients with severe trauma in a nationwide trauma registry. The age-related differences in accuracy for predicting inhospital mortality were also evaluated for the Injury Severity Score (an anatomically estimated severity score) and the Revised Trauma Score (a severity score based on physiologic status [ie, status of consciousness, respiratory, and circulation] on arrival at an emergency department [ED]).

MATERIALS AND METHODS

Study Design and Setting

This was a retrospective observational study that comprehensively evaluated age-related differences in the characteristics and outcomes of patients with severe trauma, using 2004 to 2015 data from the Japan Trauma Data Bank, which is a nationwide trauma registry. Japan currently has the most aged population in the world, and the official results from a national population-based demographic survey[8] during the study period are shown in Figure E1, available online at http://www.annemergmed.com.

The Japan Trauma Data Bank was established in 2003, and it is authorized and maintained by the Japanese Association for the Surgery of Trauma and Japanese Association for Acute Medicine. It required registration of prescribed information on all trauma patients who sustained an injury with Abbreviated Injury Scale score greater than or equal to 3 in any anatomic region. Trained registrars in each participating facility completed the registration through an online registration system. The Japan Trauma Data Bank had received records from 256 hospitals at the end of 2015, of which 95% were government-approved tertiary emergency hospitals. The database includes information in regard to injury mechanism; baseline patient characteristics, including vital signs at the scene of injury and at ED arrival; anatomic injury severity based on the Abbreviated Injury Scale and the Injury Severity Score; procedures that were performed before and after ED arrival; and status at hospital discharge (ie, deceased or alive).

This study complied with the principles of the 1964 Helsinki Declaration and its later amendments and was approved by the institutional review board of the Tokyo Medical and Dental University (2192). The requirement for informed consent from each patient was waived because of the retrospective design and the use of anonymized patient and hospital data.

Selection of Participants

We included trauma patients who were registered in the Japan Trauma Data Bank between January 2004 and December 2015 and had a severe injury in any anatomic region, defined by Abbreviated Injury Scale score greater than or equal to 3. We excluded patients who had missing data in regard to age, Revised Trauma Score, Injury Severity Score, or status at hospital discharge (ie, complete case analysis).

Methods of Measurement

We collected the following information from the Japan Trauma Data Bank: unique hospital identifier, age, sex, comorbidities (cardiovascular disease, respiratory disease, digestive disease, renal disease, cerebrovascular disease, endocrine disease, neuropsychological disorders, and malignancy), year of injury, mechanism of injury (driver in motor vehicle crash, passenger in motor vehicle crash, pedestrian or cyclist in motor vehicle crash, fall from height, ground-level falls, and others), Injury Severity Score, Abbreviated Injury Scale score for each anatomic region, systolic blood pressure at ED arrival, respiratory rate at ED arrival, Glasgow Coma Scale (GCS) score at ED arrival, and status at hospital discharge (survived or deceased). The Revised Trauma Score was retrospectively calculated with the values for systolic blood pressure, respiratory rate, and GCS score on arrival at an ED. The details of the injury mechanism categories are shown in Table E1, available online at http://www.annemergmed.com.

Primary Data Analysis

Descriptive statistics are reported as number (percentage) for categoric variables and as mean (SD) or median (interquartile range) for numeric or ordered variables, as appropriate. Because characteristics of the trauma patients were assessed with age categories (10-year intervals), the present study defined geriatric patients as being aged 60 years or older. The risks of inhospital mortality for each age group were compared by using a generalized linear mixed-effects model that was adjusted for fixed-effect variables (Injury Severity Score, Revised Trauma Score, and year of injury; these were selected according to the variables used in the Trauma and Injury Severity Score,[9] a widely used case-mix adjustment model in trauma, and the progress in the quality of trauma care[10]), as well as a random-effect variable (unique hospital identifier) to account for hospital-level clustering. No interaction term was incorporated into the model. Issues with variable multicollinearity were assessed by a variance inflation factor, and the tolerance value was set at less than 2. In this analysis, the group aged 50 to 59 years was defined as the reference category because it lay between the younger and older categories, which enabled analysis of the bidirectional changes in mortality risk for both older and younger generations. The association between age and inhospital mortality was also evaluated with a generalized additive mixed model, which was fit with the residual maximum likelihood method to account for possible nonlinear association. In the generalized additive mixed model, patient age was incorporated as a continuous variable and a smoothing term, with adjustment for the variables used in the generalized linear mixed-effects model analysis. We also evaluated the diagnostic accuracy of the Injury Severity Score and Revised Trauma Score for predicting inhospital mortality in each age category, using the area under the receiver operating characteristic curve (AUROC). The 95% confidence intervals were calculated with 2,000 stratified bootstrap replicates.

Because the crude data did not contain complete information for some variables, including the variables used for calculating the Revised Trauma Score, we also performed a multiple imputation analysis with chained equations and generated 15 data sets. Descriptive statistics were obtained after pooling all of the data sets into a single one. Point estimates and their 95% confidence intervals in predictive statistics were obtained by integrating across the imputed data sets according to the rule established by Rubin.[11] Further details in regard to the multiple imputation analysis are shown in Appendix E1, available online at http://www.annemergmed.com. All statistical analyses were performed with R software (version 3.4.1; R Foundation for Statistical Computing, Vienna, Austria). Two-sided $P<.05$ was considered statistically significant.

RESULTS

Characteristics of Study Subjects

A flow diagram of patient selection is shown in Figure E2, available online at http://www.annemergmed.com. A total of 127,303 patients with severe trauma were analyzed, of whom 16,280 (12.8%) died during hospitalization. Penetrating injuries were observed for only 3,661 patients (2.9%). Although male patients composed approximately 70% of individuals with severe trauma in the generations younger than 70 years, the proportion decreased among geriatric patients and accounted for only 24.1% among patients aged 90 years or older. The characteristics of patients with complete data according to age category are shown in Table 1. In terms of patient comorbidities (Table E2, available online at http://www.annemergmed.com), psychological disease was relatively common in patients younger than 50 years, whereas the proportions of cardiovascular diseases, stroke, hypertension, diabetes mellitus, and dementia tended to increase with age. The transitional changes in proportions between 2004 and 2015 according to age category are shown in Figure E3 and Table E3, available online at http://www.annemergmed.com. The proportion of geriatric patients aged 60 years or older increased from 31.9% in 2004 to 59.7% in 2015. Patients aged 60 years or older accounted for the majority of severe trauma cases after 2011. The crude data for the patients' characteristics, including information about missing data, are summarized in Tables E4 and E5, available online at http://www.annemergmed.com.

Main Results

Figure 1 shows the proportions of the mechanisms of injury according to age category. The prevalence of patients who were injured in a motor vehicle crash peaked for those aged 10 to 29 years, with a subsequent decrease at older ages. In contrast, the prevalence of patients with ground-level falls markedly increased with age and became the most common mechanism of injury among individuals aged 50

Table 1. Characteristics of the patients according to age category (cases with complete data).

	Category, Years									
Characteristics	**0–9**	**10–19**	**20–29**	**30–39**	**40–49**	**50–59**	**60–69**	**70–79**	**80–89**	**≥90**
Number of subjects, n	3,455	8,193	11,178	10,817	12,238	14,106	20,015	21, 952	19,756	5,593
Male sex, No. (%)	2,333 (67.5)	6,182 (75.5)	8,412 (75.3)	8,361 (77.3)	9,514 (77.7)	10,581 (75.0)	13,843 (69.2)	12,534 (57.1)	8,189 (41.5)	1,348 (24.1)
Penetrating injury, No. (%)	36 (1.0)	131 (1.6)	437 (3.9)	559 (5.2)	623 (5.1)	559 (4.0)	610 (3.0)	426 (1.9)	228 (1.2)	52 (0.9)
Mechanism of injury										
Motor vehicle crash, driver, No. (%)	9 (0.3)	2,689 (32.8)	5,017 (44.9)	3,766 (34.8)	3,902 (31.9)	3,430 (24.3)	3,401 (17.0)	2,607 (11.9)	1,127 (5.7)	66 (1.2)
Motor vehicle crash, passenger, No. (%)	252 (7.3)	821 (10.0)	659 (5.9)	354 (3.3)	310 (2.5)	376 (2.7)	516 (2.6)	645 (2.9)	393 (2.0)	47 (0.8)
Motor vehicle crash, pedestrian or bicycle, No. (%)	1,623 (47.0)	2,194 (26.8)	1,190 (10.6)	1,388 (12.8)	1,720 (14.1)	2,346 (16.6)	3,781 (18.9)	4,493 (20.5)	2,812 (14.2)	285 (5.1)
Fall from height, No. (%)	448 (13.0)	831 (10.1)	2,026 (18.1)	2,241 (20.7)	2,156 (17.6)	2,075 (14.7)	2,657 (13.3)	1,737 (7.9)	758 (3.8)	82 (1.5)
Ground-level fall, No. (%)	838 (24.3)	545 (6.7)	675 (6.0)	1,196 (11.1)	2,095 (17.1)	3,792 (26.9)	7,327 (36.6)	10,995 (50.1)	13,881 (70.3)	4,964 (88.8)
Other, No. (%)	285 (8.2)	1,113 (13.6)	1,611 (14.4)	1,872 (17.3)	2,055 (16.8)	2,087 (14.8)	2,333 (11.7)	1,475 (6.7)	785 (4.0)	149 (2.7)
Severe head injury, No. (%)	1,950 (56.4)	3,717 (45.4)	4,233 (37.9)	3,820 (35.3)	4,315 (35.3)	5,471 (38.8)	8,623 (43.1)	9,819 (44.7)	7,296 (36.9)	1,291 (23.1)
Severe neck injury, No. (%)	27 (0.8)	164 (2.0)	239 (2.1)	186 (1.7)	189 (1.5)	142 (1.0)	181 (0.9)	152 (0.7)	83 (0.4)	14 (0.3)
Severe face injury, No. (%)	8 (0.2)	27 (0.3)	70 (0.6)	86 (0.8)	98 (0.8)	105 (0.7)	133 (0.7)	101 (0.5)	53 (0.3)	5 (0.1)
Severe chest injury, No. (%)	804 (23.3)	2,702 (33.0)	4,683 (41.9)	4,494 (41.5)	5,118 (41.8)	5,356 (38.0)	6,428 (32.1)	5,755 (26.2)	3,246 (16.4)	448 (8.0)
Severe abdominal injury, No. (%)	305 (8.8)	1,057 (12.9)	1,442 (12.9)	1,288 (11.9)	1,219 (10.0)	1,216 (8.6)	1,470 (7.3)	1,203 (5.5)	653 (3.3)	73 (1.3)
Severe spinal injury, No. (%)	51 (1.5)	686 (8.4)	1,353 (12.1)	1,461 (13.5)	1,761 (14.4)	2,167 (15.4)	3,336 (16.7)	2,920 (13.3)	1,631 (8.3)	207 (3.7)
Severe upper extremity injury, No. (%)	429 (12.4)	720 (8.8)	975 (8.7)	991 (9.2)	1,068 (8.7)	1,032 (7.3)	1,199 (6.0)	1,076 (4.9)	701 (3.5)	116 (2.1)
Severe pelvis or lower extremity injury, No. (%)	577 (16.7)	2,113 (25.8)	3,366 (30.1)	3,199 (29.6)	3,300 (27.0)	3,525 (25.0)	4,955 (24.8)	7,034 (32.0)	9,957 (50.4)	3,948 (70.6)
Severe surface injury, No. (%)	0	4 (0.0005)	10 (0.1)	8 (0.1)	4 (0.0003)	4 (0.0003)	3 (0.0001)	2 (0.00009)	2 (0.0001)	1 (0.0002)
ISS, mean (SD)	17.0 (10.3)	19.3 (12.0)	20.9 (13.4)	20.8 (13.5)	20.2 (12.8)	19.7 (12.0)	19.4 (11.7)	18.6 (11.7)	16.0 (10.7)	12.8 (8.3)
ISS, median (IQR)	16 (9–20)	16 (10–25)	17 (10–26)	17 (10–26)	17 (10–25)	16 (10–25)	16 (10–25)	16 (9–25)	10 (9–19)	10 (9–13)
RTS, mean (SD)	6.99 (1.64)	6.96 (1.82)	6.70 (2.19)	6.66 (2.28)	6.75 (2.19)	6.85 (2.07)	6.90 (1.96)	7.00 (1.83)	7.21 (1.57)	7.44 (1.21)
RTS, median (IQR)	7.84 (6.90–7.84)	7.84 (6.90–7.84)	7.84 (6.82–7.84)	7.84 (6.90–7.84)	7.84 (6.90–7.84)	7.84 (6.90–7.84)	7.84 (6.90–7.84)	7.84 (6.90–7.84)	7.84 (7.55–7.84)	7.84 (7.84–7.84)

ISS, Injury Severity Score; *IQR*, Interquartile range; *RTS*, Revised Trauma Score.

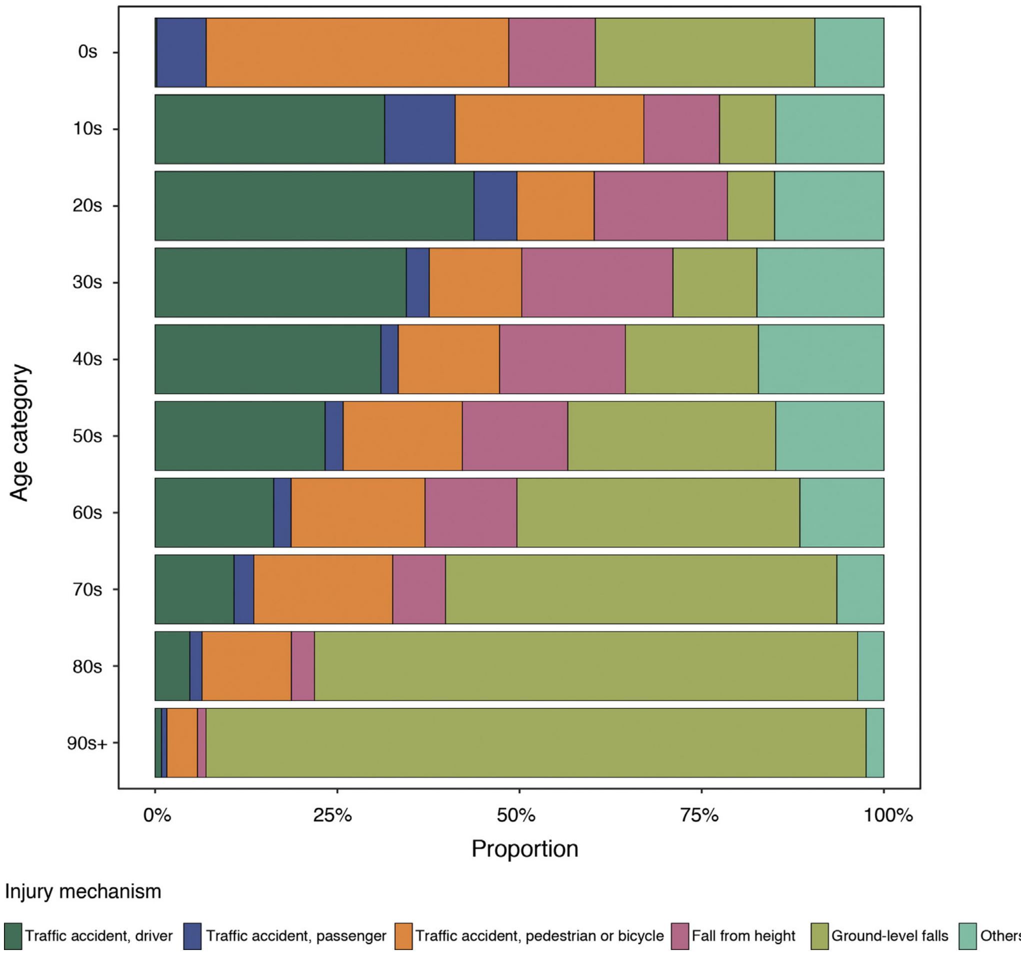

Figure 1. Mechanism of injury according to age category.

years or older. Ground-level falls accounted for 74.3% of injuries among individuals aged 80 years or older.

The proportions of the region of severe injuries (defined by Abbreviated Injury Scale score ≥3) at the head, chest, abdomen, spine, upper extremities, and pelvis and lower extremities according to age category are shown in Figure 2. The proportions at the face, neck, and surface are shown in Figure E4, available online at http://www.annemergmed.com. The proportion of severe trunk injury peaked for patients aged 20 to 49 years, with a subsequent decrease at older ages. The proportion of severe pelvic and lower extremity injuries increased significantly among individuals aged 80 years or older. Figure 3 shows the differences in Injury Severity Score and Revised Trauma Score according to age category. Lower mean and median Injury Severity Score values were observed in patients aged 80 years and older relative to their younger counterparts, which suggested that the older patients experienced less severe injuries from an anatomic perspective. However, unlike the trend in the Injury Severity Score values, the median Revised Trauma Score values were well maintained throughout all age categories, which indicated that the vital signs of most trauma patients did not deteriorate. Furthermore, the gradual age-related increase in the mean Revised Trauma Score values suggests that extremely severe cases, from a physiologic perspective, were less common in the geriatric groups than in those aged 20 to 59 years.

The results of the generalized linear mixed-effects model analysis for the associations of age category with inhospital mortality are shown in Table 2. The variance inflation factors of age, Injury Severity Score, Revised Trauma Score, and year of injury were 1.11, 1.05, 1.07, and 1.00, respectively, indicating that the statistically problematic multicollinearity did not exist in our model. After controlling for injury severity and hospital-level clustering, and relative to the reference generation (50 to 59 years), the adjusted risk of inhospital mortality increased steadily with increasing age and decreased steadily at younger ages. The generalized additive mixed-model plot for the association of age (continuous valuable) with inhospital mortality is

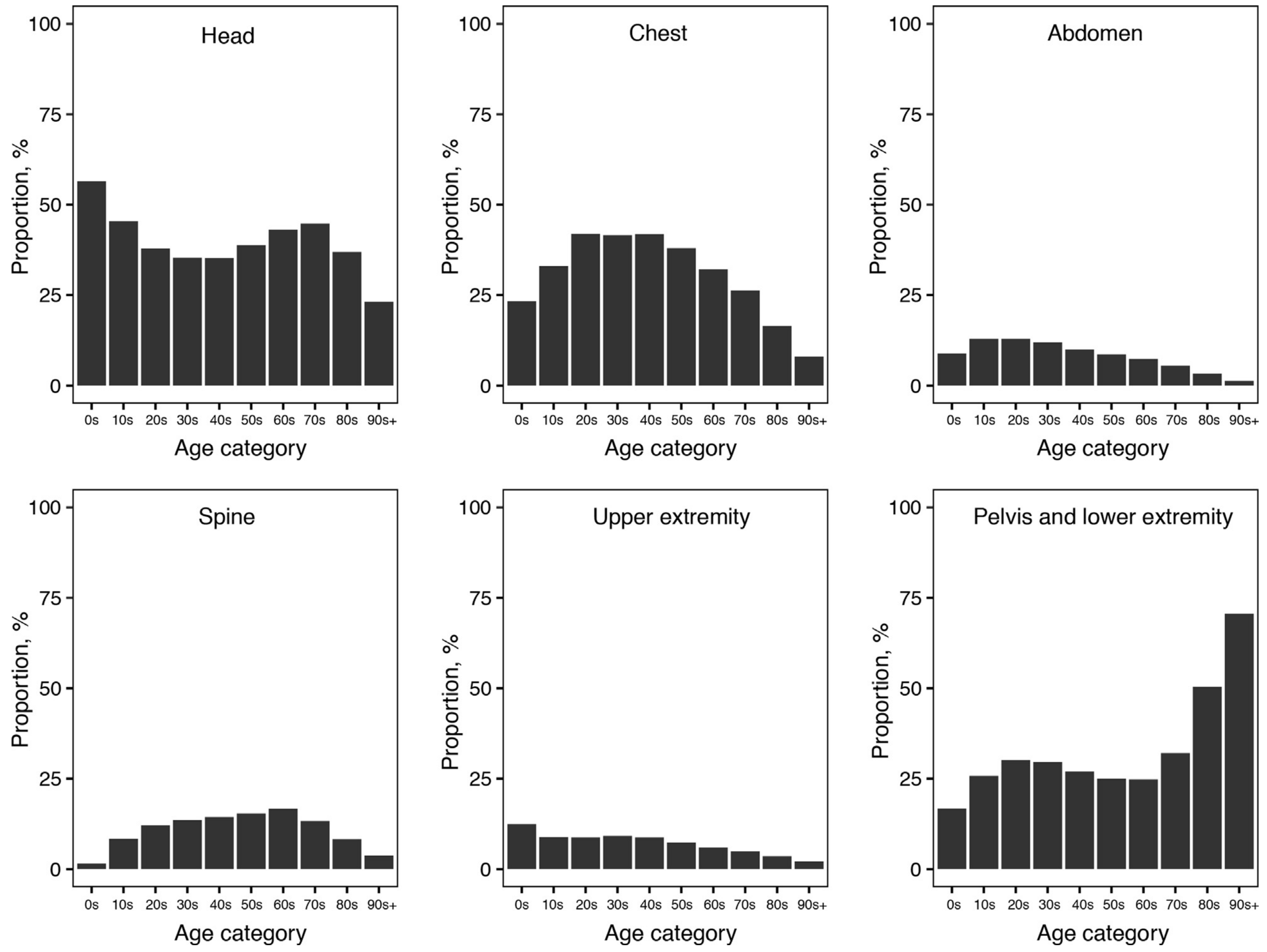

Figure 2. The proportions of severe injuries (Abbreviated Injury Scale score ≥3) according to injury location and age category in regard to the head, chest, abdomen, spine, upper extremities, and pelvis and lower extremities.

shown in Figure E5, available online at http://www.annemergmed.com. This nonlinear model showed that the risk of inhospital mortality increased steadily, with no specific threshold for a sharp increase in that risk. Nevertheless, geriatric patients had a lower mean Injury Severity Score without a significantly worsened Revised Trauma Score.

We therefore evaluated the accuracy of the Injury Severity Score and Revised Trauma Score for predicting inhospital mortality in each age category according to the AUROC values. Although the AUROC values in regard to Injury Severity Score were similar among all generations except for those aged 90 years or older, the AUROC values in regard to Revised Trauma Score decreased rapidly for those aged 70 years or older, which suggested that the Revised Trauma Score had relatively low predictive accuracy among geriatric trauma patients (Table 3).

Demographic and clinical characteristics in the multiply imputed cohort of 167,339 patients are presented in Tables E6 and E7, available online at http://www.annemergmed.com. No significant differences were observed in the demographic characteristics between the complete cases cohort and multiply imputed cohort. Furthermore, the multiple imputation cohort still exhibited a steady age-related increase in the risk for inhospital mortality according to the generalized linear mixed-effects model and generalized additive mixed model (Table E8 and Figure E6, respectively [available online at http://www.annemergmed.com]). In regard to the accuracy of the Injury Severity Score and Revised Trauma Score for predicting inhospital mortality, consistent with the analysis of cases with complete data, the multiple imputation cohort had lower AUROC values for the Revised Trauma Score in older generations, especially among patients aged 70 years or older, whereas the AUROC values for the Injury Severity Score remained relatively constant among all generations (Table E9, available online at http://www.annemergmed.com).

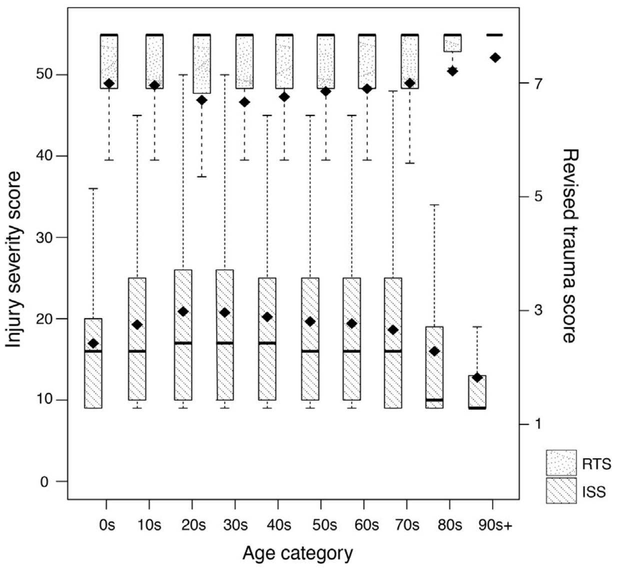

Figure 3. Injury Severity Score and Revised Trauma Score according to age category. A box plot shows median value (horizontal bold line), interquartile ranges (boundaries of the box), maximum or minimum values excluding outliers (vertical dotted lines), and mean value (diamonds). A higher ISS (1 to 75) indicates more severe injury. A lower RTS (0 to 7.8408) indicates more severe injury.

LIMITATIONS

First, because this was a retrospective study using data from a trauma registry, information from the limited number of hospitals participating in the registry was analyzed. Furthermore, given the nature of the registry, we analyzed only subjects with an Abbreviated Injury Scale score greater than or equal to 3; therefore, we generally did not include patients with relatively minor injuries, such as single distal extremity fractures. In addition, an increasing number of hospitals have begun to participate in the Japan Trauma Data Bank, and this factor may have affected the changes in the proportion of geriatric trauma patients, depending on the area and population served by the newly participating hospitals. This might have introduced selection bias into our analysis and prevented elucidation of all of the geriatric trauma burden. However, in mortality analysis, we used random-effect models to account for hospital-level clustering in the present study to compensate for this limitation. Second, because the patients were categorized into 10-year age groups, we defined geriatric patients as aged 60 years or older, whereas most previous studies have defined these patients as aged 65 years or older. However, the present study aimed to examine age-related differences in the characteristics of trauma patients, rather than to directly compare specific age groups (eg, patients <65 versus ≥65 years). Third, it was possible that some patients, especially geriatric ones, had do-not-resuscitate orders, which might cause the risk for overestimation of poor outcomes in this study; however, the Japan Trauma Data Bank does not include information about these orders. Fourth, although the findings of this study provided potentially useful information, especially for many developed countries with the issue of an aging population, some variance will exist because of specific environmental and epidemiologic factors that influence other countries' trauma systems. Further studies are needed to validate whether our findings are applicable in other countries.

Table 2. Results of the multivariable mixed-effects regression analysis according to age category (cases with complete data).

Age Category, Years	Inhospital Mortality/ Total, No. (%)	Adjusted Odds Ratio (95% CI)
0–9	210/3,455 (6.1)	0.35 (0.27–0.45)
10–19	687/8,193 (8.4)	0.41 (0.35–0.49)
20–29	1,390/11,178 (12.4)	0.51 (0.44–0.59)
30–39	1,401/10,817 (13.0)	0.52 (0.45–0.60)
40–49	1,561/12,238 (12.8)	0.78 (0.68–0.89)
50–59	1,744/14,106 (12.4)	1 [Reference]
60–69	2,743/20,015 (13.7)	1.60 (1.44–1.78)
70–79	3,254/21,952 (14.8)	2.52 (2.27–2.80)
80–89	2,685/19,756 (13.6)	4.06 (3.63–4.55)
≥90	605/5,593 (10.8)	6.09 (5.14–7.21)

Table 3. Accuracy of the Injury Severity Score and the Revised Trauma Score for predicting inhospital mortality according to age category (cases with complete data).

	AUROC (95% CI)	
Age Category, Years	ISS	RTS
0–9	0.870 (0.843–0.897)	0.977 (0.968–0.987)
10–19	0.873 (0.859–0.887)	0.970 (0.963–0.977)
20–29	0.860 (0.849–0.870)	0.970 (0.965–0.975)
30–39	0.857 (0.846–0.868)	0.968 (0.962–0.973)
40–49	0.846 (0.835–0.857)	0.963 (0.957–0.969)
50–59	0.829 (0.819–0.840)	0.947 (0.940–0.953)
60–69	0.830 (0.822–0.839)	0.924 (0.917–0.930)
70–79	0.833 (0.825–0.841)	0.892 (0.885–0.899)
80–89	0.833 (0.824–0.841)	0.867 (0.859–0.876)
≥90	0.819 (0.800–0.839)	0.792 (0.771–0.813)

DISCUSSION

The present study involved a comprehensive analysis of the Japan Trauma Data Bank, which likely contains data for the highest proportion of geriatric patients in the world.

This enabled us to evaluate detailed characteristics of geriatric trauma patients by analyzing a larger number of patients than previous studies have. Some of the results corroborated previously reported geriatric-specific trauma characteristics, such as a higher incidence of ground-level falls and an increase in pelvic and lower extremity injuries. However, this study also revealed several novel characteristics, including an age-related decrease in the prognostic accuracy of the Revised Trauma Score, lower anatomic trauma severity in the geriatric population, and a steady age-related increase in the risk of mortality.

Geriatric trauma patients have become increasingly common in many developed countries, which is related to population aging. It was reported that the proportion of geriatric patients in US trauma centers increased from 23% in 2003 to 30% in 2009.[1] An increase in geriatric trauma patients has also been reported in other countries, with 47.8% of patients in the Dutch Trauma Registry aged 65 years or older in 2014.[11] More than 50% of the patients registered in the Japan Trauma Data Bank were aged 60 years or older after 2011, and this proportion continually increased during the study period. Thus, our findings could provide information in regard to the geriatric-specific characteristics of trauma, which would help other countries face the issues that are inherent in aging populations.

Severe injuries are usually caused by high-energy trauma, such as falls from height and motor vehicle crashes.[1] The present study confirmed that these mechanisms are the cause of most trauma in patients younger than 50 years. However, the trauma mechanisms were noticeably different between the geriatric and younger generations. Several previous studies have demonstrated that elderly trauma patients have most commonly experienced a fall.[2,4,12] Similarly, we found that ground-level falls were the most common mechanism of injury among patients older than 60 years. It has also been reported that more than one third of elderly patients returned to the hospital or died within 1 year after an ED admission because of a fall,[1,13,14] and low-level falls reportedly accounted for more than 50% of deaths from trauma among patients older than 60 years.[15,16] These results suggest that low-level-fall injuries would have serious effects on the health of geriatric patients, although such falls are not usually considered a cause of severe trauma among younger patients.

The present study and previous studies have indicated that the most commonly injured body region among geriatric patients is the pelvis and lower extremities.[3,17] A previous study revealed that lower extremity fractures among patients older than 65 years were associated with approximately double the risk of mortality relative to that of younger patients.[18] Another study reported that most mortality among elderly trauma patients occurs later after injury relative to that of younger patients, even if the injuries were not immediately life threatening.[19] The activity level among older patients likely decreases as a result of injury, which might prolong hospitalization and cause the development of secondary complications, such as deep venous thrombosis, pneumonia, and delirium.[20,21] The present study categorized injured regions according to the 9 parts from the Abbreviated Injury Scale scoring system. Therefore, detailed analyses were not possible for pelvic and lower extremity injuries, which are the most common in geriatric patients. Further studies are needed to better evaluate these injuries because the severity is generally different between pelvic injuries and other lower extremity injuries.

The decreased Injury Severity Score and well-maintained Revised Trauma Score, which were observed in the geriatric generations, implied that geriatric trauma patients experienced fewer severe anatomic injuries and had well-maintained vital signs on arrival at an ED. However, the present study also revealed that inhospital mortality increased steadily and significantly with age, even after adjustment for the anatomic and physiologic injury severity (ie, Injury Severity Score and Revised Trauma Score). This discrepancy could be considered the major characteristic of geriatric trauma patients.

In this study, we found that the Revised Trauma Score, which is the most common physiologic injury severity score, had age-related decreases in its ability for predicting inhospital mortality. This could be partially explained by various physiologic derangements and coexisting diseases that could decrease the physiologic reserve of geriatric trauma patients.[22-24] The low predictability in the current trauma severity model among the elderly could result in several unfavorable situations in aging populations. From a clinical perspective, the Revised Trauma Score cannot serve as a direct measure of trauma care practice because it requires complicated calculation. However, much clinical evidence in traumatology has been established with the Revised Trauma Score or Trauma and Injury Severity Score (calculated according to age, trauma mechanism, Revised Trauma Score, and Injury Severity Score). This means that the results from future clinical researches involving an aged population and using the inadequate case-mix adjustment model could result in biased conclusions. That is, the limited predictability of the Revised Trauma Score among the elderly could mislead clinicians and influence clinical practice indirectly. Other studies have also reported the issues of geriatric-specific characteristics of trauma patients.[25] Zhao et al[26] developed a prognostic score for geriatric trauma patients, the Geriatric Trauma Outcome

Score, that was based on age, Injury Severity Score, and transfusion requirement during the first 24 hours of hospital admission. Although the prognostic accuracy of the Geriatric Trauma Outcome Score for inhospital mortality was validated in a separate study,[27] its predictive performance for 1-year mortality was reported to be insufficient.[28] Moreover, because the score requires information about blood transfusion performed during the first 24 hours, it can be determined only at 24 hours after ED arrival, and the decision for implementation of transfusion would vary, depending on each hospital or physician. Further studies to establish a novel scoring system that could be useful in clinical settings are necessary for improving patient outcomes and evaluating trauma quality in aging populations.

In summary, an analysis of a trauma registry in a country with the most aged population in the world revealed that the characteristics of patients with severe trauma varied widely according to age, with a steady age-related increase in the risk of mortality despite the lower anatomic severity of injuries. Furthermore, because of the limited ability of the Revised Trauma Score for predicting mortality among geriatric trauma patients, an alternative scoring system is needed to better grade trauma severity in geriatric patients for future epidemiologic studies in countries with aging populations.

The authors acknowledge Editage (https://www.editage.jp) for English-language editing.

Supervising editor: Timothy F. Platts-Mills, MD, MSc

Author affiliations: From the Trauma and Acute Critical Care Medical Center, Tokyo Medical and Dental University Hospital of Medicine, Bunkyo-ku, Tokyo (Kojima, Endo, Shiraishi, Otomo); and the Emergency and Trauma Center, Kameda Medical Center, Kamogawa, Chiba, Japan (Shiraishi).

Author contributions: MK and AE were responsible for drafting the article and for study supervision. All authors were responsible for revising the article and for interpretation of data, and accept responsibility for conduct of research and final approval. MK, AE, and AS were responsible for study concept and design and for statistical analysis. AE was responsible for obtaining funding. AS was responsible for acquisition of data. AE takes responsibility for the paper as a whole.

All authors attest to meeting the four ICMJE.org authorship criteria: (1) Substantial contributions to the conception or design of the work; or the acquisition, analysis, or interpretation of data for the work; AND (2) Drafting the work or revising it critically for important intellectual content; AND (3) Final approval of the version to be published; AND (4) Agreement to be accountable for all aspects of the work in ensuring that questions related to the accuracy or integrity of any part of the work are appropriately investigated and resolved.

Funding and support: By *Annals* policy, all authors are required to disclose any and all commercial, financial, and other relationships in any way related to the subject of this article as per ICMJE conflict of interest guidelines (see www.icmje.org). The authors have stated that no such relationships exist. This work was supported by the Grants-in-Aid for Scientific Research (17K17045) from the Japan Society for the Promotion of Science.

Publication dates: Received for publication July 2, 2018. Revisions received September 7, 2018, and September 18, 2018. Accepted for publication September 28, 2018. Available online November 15, 2018.

REFERENCES

1. Adams SD, Holcomb JB. Geriatric trauma. *Curr Opin Crit Care*. 2015;21:520-526.
2. Giannoudis PV, Harwood PJ, Court-Brown C, et al. Severe and multiple trauma in older patients: incidence and mortality. *Injury*. 2009;40:362-367.
3. Kocuvan S, Brilej D, Stropnik D, et al. Evaluation of major trauma in elderly patients—a single trauma center analysis. *Wien Klin Wochenschr*. 2016;128:535-542.
4. Brown CVR, Rix K, Klein AL, et al. A comprehensive investigation of comorbidities, mechanisms, injury patterns, and outcomes in geriatric blunt trauma patients. *Am Surg*. 2016;82:1055-1062.
5. Taylor MD, Tracy JK, Meyer W, et al. Trauma in the elderly: intensive care unit resource use and outcome. *J Trauma*. 2002;53: 407-414.
6. Calvo RY, Lindsay SP, Edland SD, et al. The differential associations of preexisting conditions with trauma-related outcomes in the presence of competing risks. *Injury*. 2016;47:677-684.
7. Nagy KK, Smith RF, Roberts RR, et al. Prognosis of penetrating trauma in elderly patients: a comparison with younger patients. *J Trauma*. 2000;49:190-193.
8. Statistics Bureau, Ministry of Internal Affairs and Communications. Portal site of official statistics of Japan. Available at: https://www.e-stat.go.jp/en. Accessed August 29, 2018.
9. Boyd CR, Tolson MA, Copes WS. Evaluating trauma care: the TRISS method. Trauma Score and the Injury Severity Score. *J Trauma*. 1987;27:370-378.
10. Endo A, Shiraishi A, Matsui H, et al. Assessment of progress in early trauma care in Japan over the past decade: achievements and areas for future improvement. *J Am Coll Surg*. 2017;224:191-198.e5.
11. Rubin DB. *Multiple Imputation for Nonresponse in Surveys*. New York, NY: John Wiley; 1987.
12. de Vries R, Reininga IHF, Pieske O, et al. Injury mechanisms, patterns and outcomes of older polytrauma patients—an analysis of the Dutch Trauma Registry. *PLoS One*. 2018;13:e0190587.
13. Liu SW, Obermeyer Z, Chang Y, et al. Frequency of ED revisits and death among older adults after a fall. *Am J Emerg Med*. 2015;33:1012-1018.
14. Sri-On J, Tirrell GP, Bean JF, et al. Revisit, subsequent hospitalization, recurrent fall, and death within 6 months after a fall among elderly emergency department patients. *Ann Emerg Med*. 2017;70:516-521.e2.
15. Helling TS, Watkins M, Evans LL, et al. Low falls: an underappreciated mechanism of injury. *J Trauma*. 1999;46:453-456.
16. Baker SP, Harvey AH. Fall injuries in the elderly. *Clin Geriatr Med*. 1985;1:501-512.
17. Victorino GP, Chong TJ, Pal JD. Trauma in the elderly patient. *Arch Surg*. 2003;138:1093-1098.
18. Somersalo A, Paloneva J, Kautiainen H, et al. Increased mortality after lower extremity fractures in patients <65 years of age. *Acta Orthop*. 2016;87:622-625.

19. Perdue PW, Watts DD, Kaufmann CR, et al. Differences in mortality between elderly and younger adult trauma patients: geriatric status increases risk of delayed death. *J Trauma*. 1998;45:805-810.
20. Niikura T, Sakai Y, Lee SY, et al. Rate of venous thromboembolism after complex lower-limb fracture surgery without pharmacological prophylaxis. *J Orthop Surg (Hong Kong)*. 2015;23:37-40.
21. Ahmed I, Graham JE, Karmarkar AM, et al. In-patient rehabilitation outcomes following lower extremity fracture in patients with pneumonia. *Respir Care*. 2013;58:601-606.
22. Pickering SA, Esberger D, Moran CG. The outcome following major trauma in the elderly. Predictors of survival. *Injury*. 1999;30:703-706.
23. Morris JA Jr, MacKenzie EJ, Edelstein SL. The effect of preexisting conditions on mortality in trauma patients. *JAMA*. 1990;263:1942-1946.
24. Mubang RN, Stoltzfus JC, Cohen MS, et al. Comorbidity-polypharmacy score as predictor of outcomes in older trauma patients: a retrospective validation study. *World J Surg*. 2015;39:2068-2075.
25. Demetriades D, Sava J, Alo K, et al. Old age as a criterion for trauma team activation. *J Trauma*. 2001;51:754-756.
26. Zhao FZ, Wolf SE, Nakonezny PA, et al. Estimating geriatric mortality after injury using age, injury severity, and performance of a transfusion: the Geriatric Trauma Outcome Score. *J Palliat Med*. 2015;18:677-681.
27. Cook AC, Joseph B, Inaba K, et al. Multicenter external validation of the Geriatric Trauma Outcome Score: a study by the Prognostic Assessment of Life and Limitations After Trauma in the Elderly (PALLIATE) consortium. *J Trauma Acute Care Surg*. 2016;80:204-209.
28. Ahl R, Phelan HA, Dogan S, et al. Predicting in-hospital and 1-year mortality in geriatric trauma patients using Geriatric Trauma Outcome Score. *J Am Coll Surg*. 2017;224:264-269.