The effect of age, severity, and mechanism of injury on risk of death from major trauma in Western Australia

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BACKGROUND: We examined the association between age, mechanism of injury, and Injury Severity Score (ISS) on mortality in major trauma.

METHODS: We used 9 years of population-based linked major trauma (ISS >15) registry data for Western Australia (N = 4,411). These were categorized using the Sampalis classification of injury severity: survivable (ISS 16–24), probably survivable (ISS 25–49), and nonsurvivable (ISS 50+). Age was categorized as younger than 15 years, 15 to 64 years, and 65 years or older. Multivariable linear logistic regression analysis was used to examine the risk of death.

RESULTS: Motor vehicle crashes (MVCs) were most prominent for those younger than 65 years, and falls dominated the 65 years and older group. The median ISS for the three age groups were 20, 25, and 24, respectively ($p = 0.001$). The proportion of deaths in the three groups were 7.2%, 11.5%, and 30.1%, respectively ($p = 0.0001$). Falls were the most common cause of death. The inflexion point, above which the risk of death increases exponentially, was age 47 years. For the potentially survivable ISS 25 to 49 group, the inflexion point was age 25 years. After adjusting for age and ISS, falls had the greatest risk for death (odds ratio, 1.62; 95% confidence interval, 1.21–2.18). A lower ISS had a disproportionate effect on the elderly.

CONCLUSION: The risk for major trauma death increases as age increases, with the inflexion point at age 47 years. Those younger than 15 years have a significantly lower ISS. The elderly have an increased risk for death following falls. (*J Trauma Acute Care Surg*. 2013;74: 647–651. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level II.

KEY WORDS: Major trauma; age; mechanism of injury; injury severity; mortality.

Age is an independent predictor of survival following trauma.[1,2] In the Trauma and Injury Severity Score (TRISS), it is dichotomized at an age of 55 years.[3] More recently, it has been suggested that age should be analyzed differently, with mortality increasing as age increases.[1] The proportion of patients aged 55 years or older in the Major Trauma Outcome Study (MTOS) in 1987 was 15.5%.[4] With the aging of our population, these proportions are increasing (our data have 26% aged 55 years or older). Modifying TRISS methodology, with age left as a continuous variable, performed better than the original TRISS.[5]

Although the importance of age in trauma is undisputed, few studies have investigated the effect of age on the type and severity of injuries.[6] Demetriades et al.[6] reported that age plays an important role in the anatomic distribution, severity of injuries, and survival outcomes after pedestrian injuries. It has been suggested that adults tend to have more severe pedestrian injuries than those in children,[7] and that elderly victims of pedestrian trauma have a higher Injury Severity Score (ISS).[8]

To date, these studies have concentrated on pedestrian injuries. We have 9 years of population-based major trauma data for the state of Western Australia. The purpose of this study was to examine the association between age, mechanism of injury, and ISS on mortality for the full spectrum of major trauma. Knowledge of these factors and their interrelationships may assist with their prevention and management.

PATIENTS AND METHODS

Setting

Western Australia is one of the six states of Australia and forms the western one third of Australia, with an area of 2.5 million square kilometers. Most of its area is sparsely populated, and the population at the time of this study was 1.9 million, with 69.7% in the capital city of Perth.[9] All major trauma (ISS >15) is transferred to the four tertiary hospitals in Perth, with about two thirds treated at Royal Perth Hospital. In 2009, Royal Perth Hospital was designated the State Adult Major Trauma Centre, with Royal Australasian College of Surgeons Level I Major Trauma Verification status. The Children's hospital receives patients younger than 14 years. These are the only hospitals in the state with the staff and resources for managing major trauma. There are trauma registries that cover each hospital and use identical databases and data definitions. The inclusion criteria for all the registries are trauma patients who present within 7 days of injury who are admitted for at least 24 hours and patients who die in the

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emergency department and within 24 hours of admission. Early deaths that occurred in hospitals outside of Perth before transfer are not included in this article. We have previously described this process.[10]

Design

We have previously reported an analysis of major trauma patients in Western Australia for the period July 1, 1997, to June 30, 2006. This database was developed using linked data from the state's trauma registries.[2,10] In summary, this consists of a cohort of 4,411 major trauma patients, with a median ISS of 24 (interquartile range [IQR], 17–29). These were 3,214 (72.9%) men with a mean age of 39.8 ± 23.0 years (range, 0–102 years). The main causes were motor vehicles crashes (MVCs) (2,103, 47.7%), falls (941, 21.3%), and miscellaneous other (1,367, 31.0%). Penetrating injury accounted for 4.1% of the total. Almost three fourths of miscellaneous other were: struck by object, pedal cyclist, stabbing, fire, and horse riding. Using the Sampalis categories of injury severity, there were 2,210 (50.1%) with an ISS of 16 to 24 (survivable; mean age, 39.8 years), 1,962 (44.5%) with ISS of 25 to 49 (probably survivable; mean age, 40.3 years), and 239 (5.4%) with ISS of 50+ (nonsurvivable; mean age, 36.2 years).[11] Death in the hospital occurred in 646 (14.6%).

This study was approved by the ethics committee of the University of Western Australia (RA/4/1/1329) and the Western Australian Department of Health, Human Research Ethics Committee (No. 200601).

Statistical Analysis

Descriptive analysis used percentages for categoric and ordinal variables and means for continuous variables (arithmetic or geometric, as appropriate). The ISS was described using the median for descriptive data and the geometric mean for the statistical modeling because it follows a log-normal distribution[12] (Shapiro-Wilk test for a log-normal distribution, $p = 0.717$). For analysis of categoric and ordinal variables, the likelihood ratio χ^2 test was used. The Wilcoxon rank-sum test was used for univariate analysis of continuous variables.

Multivariable linear logistic regression analysis was the first method used to examine the risk of death following major trauma. The area under the curve of the receiver operator characteristics curve was used to estimate the explanatory power of the logistic models. The adequacy of the fit for the logistic regression models was tested with the Hosmer-Lemeshow goodness-of-fit test.

Multivariable Cox proportional hazards models with Efron's method to adjust for ties in survival time were used to examine the relationship between age and time to death following injury. Harrell's concordance statistic (C) was used to estimate the explanatory power of the Cox models. The validity of the proportional hazards assumption was tested using the method of Grambsch and Therneau based on Shoenfeld residuals.[13]

Both logistic and Cox regression models assume a linear relationship between continuous independent variables, such as age and the dependent variable. This assumption is known to be invalid for the ISS measure, and it is likely to be invalid for age. Thus, many researchers use a quadratic model for these variables by incorporating ISS squared and age squared in the models. We chose to test the assumption of linearity for these variables using a specific form of transformation called a "restricted cubic spline." The restricted cubic spline was chosen because it is more appropriate than polynomial transformations for large sample sizes. The method uses an iterative procedure to fit the model to the observed data, beginning with a linear fit as the null hypothesis. This is compared with the cubic transformation for each interval of the range of the continuous variable. Points that identify a deviation from linearity (inflexion points) are termed "knots," and the transformation of the variable changes at each knot. The restriction of the spline ensures that there is a linear slope adjacent to each knot, so that there is a smooth transition at the knots, which produces a smooth line throughout the range of the independent variable. A likelihood ratio χ^2 test was used to determine whether the models were equivalent and the Akaike information criterion (AIC) was used to compare the spline models with their linear counterparts. This is necessary because the AIC incorporates a penalty for models that have a greater number of independent covariates as the spline models do. The model that minimized the AIC was chosen as the best fit when the models were significantly different.

A value of $p < 0.05$ was regarded as statistically significant for all analyses. The analysis was conducted using the Stata statistical package, Version 12 (StataCorp., College Station, TX). The spline regression models were developed using the package written by Royston and Sauerbrei.[14]

RESULTS

The differences in the causes of trauma according to age are listed in Table 1. This highlights the prominence of MVCs in those younger than 65 years and the prominence of falls in those aged 65 years or older. The median ISS in those younger than 15 years is 20, which is significantly less than those in the older age groups. The ISS-adjusted odds ratio (OR) for death in this age group is 0.5 (95% confidence interval [95% CI], 0.32–0.78, $p = 0.002$). For MVCs only, the median ISS in the three age groups were 22, 26, and 26, respectively ($p = 0.022$). Table 2 highlights the significantly higher ISS

TABLE 1. Descriptive Data for the 4,411 Major Trauma Patients According to the Three Age Groups

Age Group, yr	<15	15–64	≥65	*p*
n (%)	345 (7.8)	3246 (73.6)	820 (18.6)	
Mean age, mean ± SD, yr	7.4 ± 4.8	33.6 ± 13.5	78.1 ± 7.8	0.0001
Male, n (%)	229 (66.4)	2,540 (78.3)	445 (54.5)	0.0001
MVC, n (%)	161 (46.7)	1,711 (52.7)	231 (28.2)	0.0001
Falls, n (%)	55 (15.9)	414 (12.8)	472 (57.6)	
Other*, n (%)	129 (37.4)	1,121 (34.5)	117 (14.3)	
Median ISS (IQR)	20 (17–26)	25 (18–30)	24 (17–26)	0.001
Admitted ICU, n (%)	196 (56.8)	1,499 (46.2)	240 (29.3)	0.0001
Median LOS (IQR), d	4 (4–19)	10 (5–20)	11 (4–24)	0.057
Death, n (%)	25 (7.2)	374 (11.5)	247 (30.1)	0.0001

*Includes machinery (work), gunshot, cutting/piercing, stabbing, explosives, hot liquid, fire, electrical, chemical, crushing, struck by object, recreational.
LOS, length of stay.

TABLE 2. Description of Cause Categories, Age, and ISS

	MVC	Falls	Other	*p*
Mean age, mean ± SD, yr	34.5 ± 19.5	59.0 ± 25.6	34.8 ± 18.8	0.0001
Median ISS (IQR)	26 (20–34)	21 (17–26)	22 (17–26)	0.003
Admitted ICU, n (%)	1,081 (51.4)	244 (25.9)	610 (44.6)	0.0001
Median LOS (IQR)	11 (6–22)	9 (3–18)	9 (4–21)	0.0001
Death, n (%)	267 (12.7)	207 (22)	172 (12.6)	0.0001

LOS, length of stay.

resulting from MVCs and the larger proportion requiring intensive care unit (ICU) management. However, the proportion of deaths is greatest in the falls group. We found a small but negative relationship between age and ICU admission (OR, 0.98; 95% CI, 0.977–0.984), but this may be influenced by clinical discretion and bed availability. Table 3 reports the more detailed falls data according to the distance fallen. The worst type of fall, without adjusting for age and ISS, is a fall from standing. However, after adjusting for age and ISS, there is no significant difference in the risk of death.

The most common cause of death in those younger than 65 years was MVCs (17, 68% for those younger than 15 years and 185, 49.5% for those aged 15–64 years). For those aged 65 years or older, the most common cause of death was falls (149, 60.3%), with 65 (26.3%) from MVCs. The median ISS of the 646 deaths was 29 (IQR, 25–45). One hundred ninety-seven (30.5%) occurred within 24 hours, and 601 (93.0%) occurred within 30 days (see Figure, Supplemental Digital Content 1, http://links.lww.com/TA/A225, displays the time to death data). The overall median time to death was 10 days (IQR, 5–21). Four hundred thirty-nine (68%) were male, and the mean age was 51.1 ± 26.5 years (range, 1–102 years). The time to death using the Sampalis categories of injury severity were as follows: ISS 16 to 24 (survivable), median time to death, 5 days (IQR, 2–13 days); ISS 25 to 49 (probably survivable), median time to death, 2 days (IQR, 1–8 days); and ISS 50+ (nonsurvivable) median time to death, 1 day (IQR, 0–2 days). Almost one half the deaths were caused by head injury. More than three fourths of all deaths were caused by either head injury or hemorrhage.

We examined the complexities of age-related mortality in trauma. Figure 1 plots the risk of death for all patients. The inflexion point is at age 47 years, with no change in the risk of death below this age and an exponential increase beyond this age. Figure 2 plots the risk of death according to the Sampalis classification of injury severity. For probably nonsurvivable injuries (ISS 50+), there is no significant relationship with age. For potentially survivable injuries (ISS 25–49), the inflexion point is age 25 years. The role of sex was not significant.

Table 4 reports the logistic regression model for risk of death according to age, ISS, and mechanism of injury (see Figure, Supplemental Digital Content 2, http://links.lww.com/TA/A226, displays this graphically*). This highlights that falls is the mechanism of injury that has the greatest risk of death, a 62% increased risk compared with MVCs after adjusting for age, ISS, and their interaction terms. This model correctly classified 82.4% of the deaths, and there was no interaction between age and cause category. The interaction between age and ISS was significant and demonstrates that the effect of ISS is greater with increasing age. Together with the curves reported in the figures, this model highlights that a lower ISS (especially the survivable category) has a disproportionate increased effect on the elderly. It also highlights the nonlinear nature of age and ISS. A summary *p* value for the overall contribution of ISS on the risk of death was $p < 0.0001$; for age, $p < 0.0001$; and cause category, $p < 0.0001$.

*This figure is not an exact representation of Table 4, because age and the age x ISS interaction are not incorporated in the estimate of ORs, but are in table 4. This figure highlights that falls are strongly age-related.

TABLE 3. Descriptive Data for the Different Types of Falls

	Fall From Standing	Fall <3 m	Fall ≥3 m	*p*
Age, mean ± SD, yr	73.6 ± 17.1	63.0 ± 21.3	40.1 ± 17.7	<0.0001
Male, n (%)	193 (54.8)	214 (66.9)	121 (81.8)	<0.0001
Median ISS (IQR)	20 (17–25)	18 (16–25)	27 (21–41)	<0.0001
Death, n (%)	103 (29.3)	69 (21.6)	29 (19.6)	0.021

DISCUSSION

Age is an important and independent predictor of survival following major trauma. We have found that the elderly have an increased risk for death following falls compared with MVCs after adjusting for injury severity. This is most prominent in the important survivable category (ISS 16–24), where there is a greater expectation of survival. Our data highlight that the inflexion point occurs at age 47 years in our population, which may allow for better targeting of age-appropriate preventive programs. This contrasts with the arbitrary dichotomy of age 55 years in TRISS and the inflexion point at age 65 years reported by Bergeron et al.[1] However, Morris et al.[15] reported that mortality increased in middle age (40–64 yrs) in patients with injuries of moderate severity.

These differences may reflect different patterns of injury, with penetrating trauma much more prominent in the United

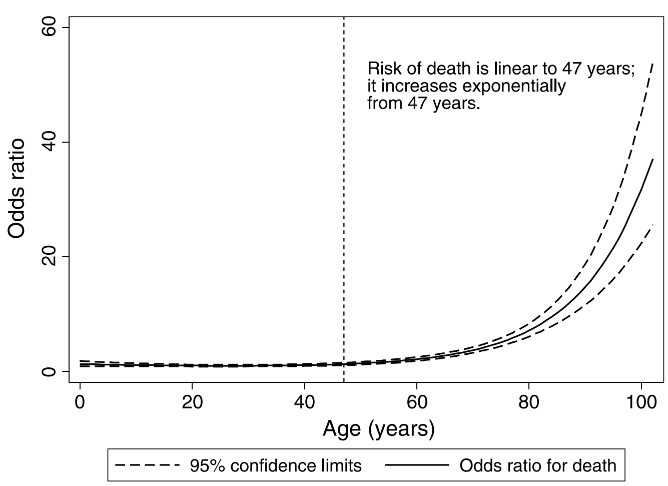

Figure 1. Risk of death for all major trauma patients. The line at 47 years shows the inflexion point identified by the spline regression. Above this age, there is an exponential increase in the risk of death.

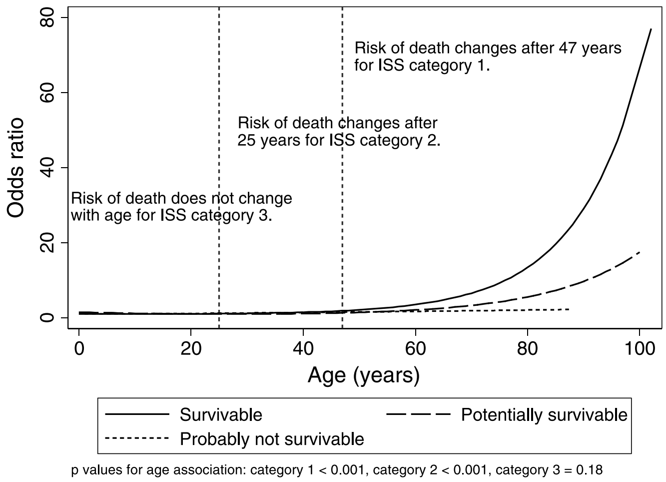

Figure 2. Risk of death for all major trauma patients according to the Sampalis classification. The curves begin with a linear part where the OR is one. The lines at 25 years and 47 years show the inflexion points identified by the spline regression for categories "potentially survivable" and "survivable," respectively. For ISS category 3, this is stable across all observed ages (1–88 years) because there is no association with age for this category. Note the different scale of the *y*-axis. Category 1, survivable, ISS 15 to 24; category 2, potentially survivable, ISS 25 to 49; category 3, probably not survivable, ISS 50+.

States.[16,17] Importantly, the inflexion point is at age 25 years for the more severely injured potentially survivable ISS 25 to 49. Conversely, age is irrelevant for a nonsurvivable injury. The "other" causes category also has a higher risk of death than MVCs but is a very heterogeneous group. Overall, age provides a greater contribution to prediction of mortality than comorbidity in the major trauma population.[5] Our data highlight that this relationship is exponential beyond the demonstrated inflexion points and not linear.

Falls have increased prominence with the elderly.[18] This prominence increases as age increases. In Australia in 2004 to 2005, the most common cause of injury death was unintentional falls, which accounted for 29% of all community injury deaths.[19] Persons aged 70 years or older accounted for almost 90% of all deaths in this group.[19] Similarly, for those aged 65 years or older, approximately three fourths of hospitalizations result from falls.[20] Trauma systems need to be aware that the elderly after falls may not display the obvious physiologic derangement seen after MVCs. This makes them seem to be deceptively uninjured, but they should be considered high risk.[21]

Although this study did not address physiologic variables, we have previously reported the relatively good initial Revised Trauma Scores in elderly falls patients.[21] This observation highlights the concept of "limited physiologic reserve" in the elderly trauma victim and spotlights a key difference between the average younger trauma patient with normal physiologic characteristics and the elderly patient with outwardly normal "numbers" but with underlying physiologic derangements.[18] The elderly may also be predisposed to poor outcomes from other factors such as medical comorbidities, medications, and susceptibility to complications.

Community awareness on mortality from major trauma tends to focus on road trauma in young males. Our results highlight that the most frequent cause of major trauma death is falls and not MVCs. Although prevention of road trauma is an important public health measure, with the aging of the population, the importance of prevention, especially falls prevention, should be emphasized. This has the potential to have a greater impact on trauma mortality, especially, in those who are older.[22] This age group is likely to comprise an increasingly important proportion of major trauma.

The other noteworthy finding is that children have less severe injuries. Our results are consistent with previous reports that focus exclusively on pedestrian injuries. Demetriades et al.[6] concluded that age plays an important role in the anatomic distribution and severity of injuries and survival outcomes after pedestrian injuries. Derlet et al.[7] reviewed 217 pedestrian injuries in Sacramento and found that hospital length of stay and severity of injuries were much worse than those in adults, although no ISSs were reported. They conclude that children generally have better outcomes than those in adults, and this is consistent with our results. Similarly, Peng and Bongard[23] found that hospital stay, ISS, Revised Trauma Score, Glasgow Coma Scale, and mortality worsen with age in their study of 5,000 injured pedestrians in Los Angeles. In a review of 273 pedestrian injuries, Kong et al.[8] reported a higher ISS in elderly victims. It is likely that the extra safety measures required for children in motor vehicles is having the desired protective effect. They are also more flexible than adults.

Our time to death data are at odds with the classic trimodal description of the temporal distribution of death from trauma.[24] However, several articles have reported their data on this subject, and none have confirmed the classic teaching.[17,22,25–27] Much significance has been placed on the trimodal distribution, with the Advanced Trauma Life Support course concentrating on the second peak of trauma deaths.[24] Consistent with other studies, our results demonstrate a positive (right) skewed temporal distribution. This change during several decades is likely to reflect the general improvements in a mature urban trauma system: in prehospital care, trauma

TABLE 4. Logistic Regression Model Reporting Risk of Death According to Age, ISS, and Cause

Variable	OR	95% CI	*p*
Age spline 1 (standardized)	3.26	2.35–4.51	<0.001
Age spline 2	0.84	0.75–0.93	0.001
ISS spline 1 (standardized)	4.56	3.53–5.88	<0.001
ISS spline 2	1.35	1.20–1.52	<0.001
ISS spline 3	0.86	0.80–0.97	0.010
Age × ISS interaction	0.9992	0.9988–0.9996	<0.001
Cause			
Falls	1.62	1.21–2.18	0.001
Other	2.06	1.57–2.70	<0.001

The reference group for cause is MVC.
Hosmer-Lemeshow goodness-of-fit, $p = 0.28$.
Area under ROC curve, 0.824.
Spline 1 subtracts the mean from each value.
Splines 2 and 3 are polynomial transformations that define the shape of the curves shown in the figures.

resuscitation care, improvements in intensive care reducing the number of late deaths, and perhaps general system improvements in society's response to trauma.

As the original second and third peaks have now been blunted, the next most important advance is prevention to address the initial peak of trauma deaths, which cannot be addressed by acute care.[24] An organized system of injury prevention is needed. The World Health Organization have declared this the decade of road safety, and this is a welcome first step.[28] This is noteworthy because road traffic injuries have become the leading cause of death among young people aged 15 to 29 years.[28]

The Advanced Cardiac Life Support system highlights the links in the chain of survival for cardiac care. This chain of survival has contributed to communicating to the public the key aspects of cardiac life support. A similar model should benefit the public's understanding of trauma care, which is an underfunded area of public health. As such, prevention should be considered the first link in the trauma care chain of survival.

There are limitations to Trauma Registry data that include concerns about completeness, quality, and limitations in coverage.[29] However, the database was developed using established data linkage techniques for the linkage of multiple, large, population-based administrative data sets. This is one of only a small number of information-rich environments worldwide.[30]

In summary, we have found that the risk for major trauma death increases as age increases, with the inflexion point at age 47 years. This inflexion point drops to age 25 years with the more severely injured. Those younger than 15 years have a significantly lower ISS. This contrasts with the elderly, who have an increased risk for death following falls compared with MVCs.

AUTHORSHIP

D.F. conceived and designed the study, obtained the data, performed analysis and data interpretation, and wrote the article. I.J. and S.L. assisted with data collection and data interpretation and critically reviewed the final version. M.P. performed the analysis and data interpretation and critically reviewed the final version.

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DISCLOSURE

The authors declare no conflicts of interest.

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