The changing nature of death on the trauma service

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Ernest E. Moore, Editor: PI, research grant, Haemonetics. Associate editors: David Hoyt, Ronald Maier, and Steven Shackford have nothing to disclose. Editorial staff: Jennifer Crebs, Jo Fields, and Angela Sauaia have nothing to disclose.

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All authors have nothing to disclose.

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Submitted: February 13, 2013, Revised: April 12, 2013, Accepted: April 15, 2013, Published online: July 2, 2013.
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This study was presented as a poster at the 70th American Association for the Surgery of Trauma Annual Meeting, September 14–17, 2011, in Chicago, Illinois.
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DOI: 10.1097/TA.0b013e3182997865

BACKGROUND: Recent innovations in care have improved survival following injury. Coincidentally, the population of elderly injured patients with preexisting comorbidities has increased. We hypothesized that this increase in elderly injured patients may have combined with recent care innovations to alter the causes of death after trauma.

METHODS: We reviewed demographics, injury characteristics, and cause of death of in-hospital deaths of patients admitted to our Level I trauma service from 2000 through 2011. Cause of death was classified as acute hemorrhagic shock; severe traumatic brain injury or high spinal cord injury; complications of preexisting medical condition only (PM); survivable trauma combined with complications of preexisting medical condition (TCoM); multiple-organ failure, sepsis, or adult respiratory distress syndrome (MOF/S/ARDS), or trauma not otherwise categorized (e.g., asphyxiation). Major trauma care advances implemented on our service during the period were identified, and trends in the causes of death were analyzed.

RESULTS: Of the 27,276 admissions, 819 (3%) eligible nonsurvivors were identified for the cause-of-death analyses. Causes of death were severe traumatic brain injury or high spinal cord injury at 44%, acute hemorrhagic shock at 28%, PM at 11%, TCoM at 10%, MOF/S/ARDS at 2%, and trauma not otherwise categorized at 5%. Mean age at death increased across the study interval (range, 47–57 years), while mean Injury Severity Score (ISS) decreased (range, 28–35). There was a significant increase in deaths because of TCoM (3.3–20.9%) and PM (6.7–16.4%), while deaths caused by MOF/S/ARDS decreased from 5% to 0% by 2007. Compared with year 2000, the annual adjusted mortality rate decreased consistently starting in 2009, after the 2002 to 2007 adoption of four major trauma practice guidelines.

CONCLUSION: Mortality caused by preexisting medical conditions has increased, while markedly fewer deaths resulted from the complications of injury. Future improvements in outcomes will require improvement in the management of elderly trauma patients with comorbid conditions. (*J Trauma Acute Care Surg*. 2013;75: 195–201. Copyright © 2013 by Lippincott Williams & Wilkins)

LEVEL OF EVIDENCE: Epidemiologic study, level III.

KEY WORDS: Death; trauma center; innovations; elderly; aging patients.

The most common causes of death from trauma have significantly changed during the last four decades.[1–5] Innovations in patient care and the development of trauma systems have improved survival following injury.[3,6–8] Advances in resuscitation strategies, operative management, and critical care guidelines are credited with significantly improved outcomes.[9–15] However, as the American population ages, patient age at injury and attendant comorbidities likewise seem to be increasing.[3–5] We hypothesized that an increase in the number of elderly injured patients with preexisting comorbidities may have combined with recent trauma care innovations to alter the cause of death after trauma. To evaluate this hypothesis, we examined the demographics, injury characteristics, and cause of death of patients admitted to our trauma service who died in-hospital during a 12-year period. Trauma care advances implemented in our service during the period were identified, and trends in the causes of death were analyzed.

PATIENTS AND METHODS

An urban Level I trauma center, Scripps Mercy Hospital, is part of the San Diego County Trauma System. Each of the system's six trauma centers participates in the peer review process at the monthly countywide Medical Audit Committee (MAC) meeting at which all injury-related deaths at each center are reviewed and opportunities for improvement are identified.[16]

With the approval of the institutional review board, demographic and injury data of patients admitted at our center from 2000 through 2011 were collected from the Scripps Mercy Trauma Registry. All in-hospital deaths were identified and subjected to a review of findings of the Scripps Mercy Trauma Quality Program. Under the program, every in-hospital death was evaluated at the trauma center's monthly multidisciplinary trauma morbidity and mortality conference and subsequently presented to the monthly MAC process. This included a review of the patient's hospital course and the San Diego County Medical Examiner's autopsy findings to determine the cause of death and identify opportunities for improvement. To further characterize the impact of trauma service management, patients who were admitted without trauma consultation were excluded from the subsequent cause-of-death analyses. Cause of death for eligible nonsurvivors was determined by a review of the San Diego County Medical Examiner autopsy findings, the medical record summary prepared for MAC, and the conclusions of the MAC review process. Causes of death were classified as acute hemorrhagic shock (AH); severe traumatic brain injury or high spinal cord injury (TBIC); complications of a preexisting medical condition only (PM); survivable trauma combined with complications of a preexisting medical condition (TCoM); any of the following complications of trauma: multiorgan failure, sepsis, or adult respiratory distress syndrome (MOF/S/ARDS); or trauma not otherwise categorized (OT) (e.g., asphyxiation).

Major changes in our trauma surgeon practice group's patient care guidelines were reviewed. During the study period, the trauma surgeon group's practice structure and pattern remained stable. Four guidelines relevant to this study were adopted during this period. Lung protective ventilation, including the use of low tidal volume and other protective ventilation strategies, was instituted in April 2002. In October 2002, an aggressive screening and prophylaxis guideline for the management of venous thromboembolic (VTE) risk was implemented. This consisted of routine venous duplex examination performed by a trained ultrasound technologist at least weekly for patients on the medical-surgical floor and biweekly for patients in the intensive care unit. It was combined with a more aggressive use of chemoprophylaxis with either low-dose unfractionated heparin or low-molecular-weight heparin. In April 2007, damage-control resuscitation

TABLE 1. Characteristics by Survivorship

	Survivors	Deaths	*p*
n	26,434	842	
Age, mean, y	41.2	51.4	<0.001
Elderly, %	16.0	34.6	<0.001
Sex (male), %	68.4	74.1	<0.001
ISS, mean	8.2	34.3	<0.001
ISS > 15, %	14.6	88.1	<0.001
1st SBP < 90 mm Hg, %	1.8	41.6	<0.001
Blunt mechanism, %	87.4	68.5	<0.001
Charlson index, %			<0.001
1	5.9	8.4	
2+	3.3	8.4	
Admission GCS score, mean	14.5	6.1	<0.001

techniques were instituted. This approach called for the infusion of red blood cells, fresh frozen plasma, and platelets in a 1:1:1 ratio when massively transfusing a patient. In the winter of 2007, the use of fresh frozen plasma was limited to male donors to reduce the incidence of transfusion-related acute lung injury (TRALI).

Statistical analysis was performed using Stata/MP version 11.2 (StataCorp LP, College Station, TX). Categorical and continuous variables were analyzed by calendar year and cause of death using Student's *t* test, analysis of variance, and χ^2 statistical tests. Linear trend tests and Cochran-Armitage test for trend were used to identify trends by calendar year. Patient comorbidities (unavailable for the first half of the study interval) were evaluated for years 2006 to 2011 by Charlson Comorbidity Index,[17] which designates a numeric weight for each comorbid condition that is proportional to the disease-related risk of death. To assess time-trends in annual mortality rates, a Poisson regression was fitted. This regression used 2000 as a reference year and was adjusted for binary age (<65 or ≥65 years), mechanism of injury, categorized Injury Severity Score (ISS) (<8, 9–15, 16–24, and 25–75), and an interaction term for age and ISS. Additional models stratified by binary age used the same variables. Owing to the interaction, additional models were stratified by elderly versus nonelderly status using the same variables. The annual trauma patient volume was log transformed and served as the denominator of each annual rate. Statistical significance was attributed to $p < 0.05$.

RESULTS

A total of 27,276 patients were admitted to the trauma center during the 12-year study period. Annual patient volume ranged from 1,925 to 2,558, with higher volumes in the latter years. Eight hundred forty-two in-hospital deaths (3.1%) were identified for initial analyses. In this cohort, mean age, ISS, and Glasgow Coma Scale (GCS) score were significantly different between survivors and nonsurvivors (Table 1). Patients who died during the 12-year study period were more likely to be elderly (65 years and older), male, severely injured (ISS > 15), and admitted with hemodynamic instability (initial systolic blood pressure [SBP] < 90 mm Hg). Blunt force injury was the predominant mechanism of injury overall. Length of stay (LOS) for all patients during the study period (2000–2011) did not show a significant directional trend (2.85–2.91 days, trend $p = 0.607$). Likewise, after stratification by survival status, LOS did not evidence significant trends (survivors: 2.87–2.95 days, trend $p = 0.508$; nonsurvivors: 2.31–3.21 days, trend $p = 0.186$).

As a percentage of annual trauma admissions, both the elderly and the severely injured increased significantly from 10.8% in 2004 to 25.5% in 2010 ($p < 0.001$) and from 14.1% in 2001 to 19.0% in 2005 ($p = 0.001$), respectively (Table 2). The percentage of patients admitted with hemodynamic instability did not change significantly. For available data,

TABLE 2. Characteristics of Overall Trauma Population by Admission Year

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Trend *p*
Trauma patient load	1,925	1,925	2,004	2,117	2,109	2,285	2,506	2,502	2,558	2,530	2,396	2,419	
Age, mean, y	37.9	38.0	38.1	39.0	37.3	38.6	40.5	41.8	44.0	45.8	47.5	46.8	<0.001
Elderly, %	12.1	11.4	12.2	12.7	10.8	12.3	14.6	16.7	19.8	21.7	25.5	24.6	<0.001
Sex (male), %	70.2	69.5	68.4	71.1	70.6	71.2	70.0	67.6	67.0	67.1	65.5	66.4	<0.001
ISS, mean	8.4	8.0	9.2	9.6	9.7	10.1	9.4	9.3	8.7	8.7	8.4	8.4	0.283
ISS > 15, %	14.7	14.1	15.9	17.4	17.5	19.0	18.1	17.7	15.9	16.5	17.3	17.3	0.016
1st SBP < 90 mm Hg, %	3.0	3.0	2.8	4.4	2.7	2.6	2.9	3.3	2.8	3.1	2.5	2.9	0.236
Blunt mechanism, %	84.0	83.6	85.4	85.0	83.2	83.3	85.1	87.9	90.3	89.9	89.9	91.9	<0.001
Charlson index, %													<0.001
1	ND	ND	ND	ND	ND	ND	9.5	10.8	10.7	11.3	11.9	11.7	
2+							5.2	5.0	6.0	6.6	7.2	8.1	
Mortality, %	3.3	3.0	3.5	4.0	3.1	3.6	3.2	3.3	2.7	2.6	2.3	2.8	0.003
Time-trend IRR													
Full sample	1.00	0.93	0.94	1.01	0.84	0.85	0.84	0.85	0.85	0.71*	0.66*	0.75*	
<65 y	1.00	1.00	0.80	0.98	0.86	0.84	.88	0.86	0.83	0.70*	0.72	0.70*	
≥65 y	1.00	0.80	1.30	1.14	0.81	0.89	0.78	0.87	0.92	0.75	0.62*	0.84	

*Statistical significance relative to year 2000.
ND, no data.

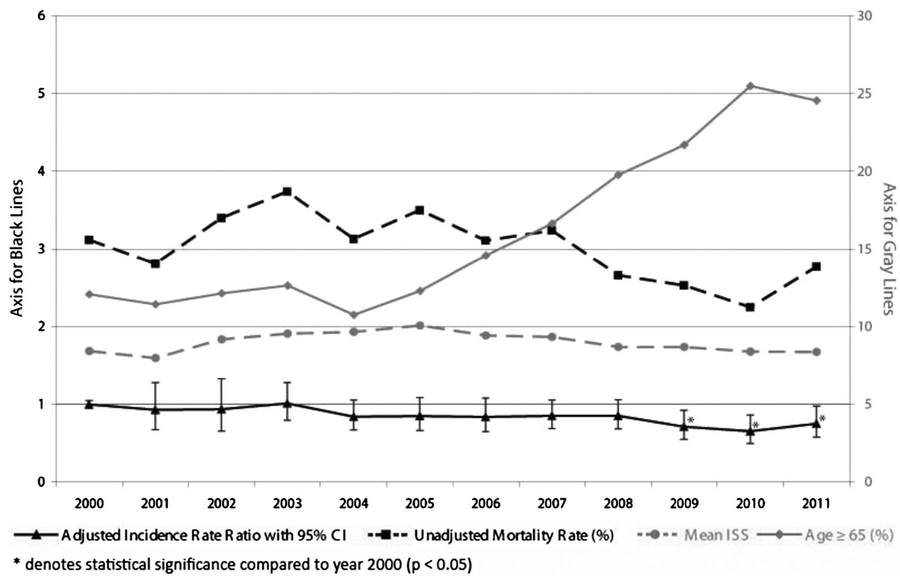

Figure 1. Annual in-hospital mortality estimates and clinical indicators by calendar year.

increasing trends in the prevalences of Charlson comorbidities were observed ($p < 0.001$). Unadjusted all-cause annual mortality rates ranged from 2.3% to 4.0%, and although not statistically different by year, there was a decreasing trend ($p = 0.003$).

Results from the time-trend analysis showed that the annual adjusted mortality rates were significantly lower in years 2009 (incidence rate ratio for mortality [IRR], 0.71; 95% confidence interval [CI], 0.55–0.92; $p = 0.010$), 2010 (IRR, 0.66; 95% CI, 0.50–0.87; $p = 0.003$), and 2011 (IRR, 0.75; 95% CI, 0.58–0.98; $p = 0.034$) with 2000 as the reference year (Table 2). In this regression, the interaction term of age and ISS was statistically significant ($p < 0.001$), indicating that a nonlinear, synergistic effect existed between injury severity and age, affecting annual mortality rates. After stratification by elderly versus nonelderly status, similar reductions in annual mortality were seen for 2009 to 2011, although regressions were affected by reduced sample size.

There was a marked increase in elderly patients beginning in 2005 concurrent with a steady mean ISS and a gradual decline in mortality over time (Fig. 1). Despite the significant increase in mortality in elderly patients, the adjusted overall mortality declined when compared with the year 2000. This decline achieved significance in 2009.

Of the 842 patients who died at the trauma center following injury, 23 (2.7%) were not managed by the trauma service and were excluded, leaving 819 nonsurvivors (97.3%) eligible for the cause of death-specific analyses. Trends over time among eligible nonsurvivors revealed significant increases in mean age and blunt injury mechanism (trend $p < 0.001$) (Table 3). Conversely, ISS gradually decreased over the study interval from a mean of 35.2 in 2000 to 28.3 in 2011. Falls displaced motor vehicle crashes as the predominant mechanism underlying blunt injury. There were no annual trends identified among penetrating injuries.

The breakdown of adjudicated causes of death were TBIC in 363 (44.3%), AH in 232 (28.3%), PM in 87 (10.6%), TCoM in 79 (9.7%), MOF/S/ARDS in 15 (1.8%), and OT in 43 (5.3%) (Table 4). Mean age was significantly different by cause, as was ISS, admission GCS score, LOS, and prevalence of admissions with hemodynamic instability. Stratification by cause of death revealed disproportionate differences in trends among causes during the study period (Fig. 2). From 2000 to 2011, deaths from TCoM and PM increased from 3.3% to 20.9% and from 6.7% to 16.4%, respectively. The proportion of deaths caused by MOF/S/ARDS decreased from 5% in 2000 to 0% in 2007. Although statistically significant decreasing trends were

TABLE 3. Deaths (n=819): Patient Characteristics by Admit Year

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	Trend *p*
Age, mean, y	47.0	47.4	51.0	47.8	46.8	50.3	47.4	52.1	53.9	57.1	58.5	56.7	<0.001
ISS, mean	35.2	34.7	40.5	35.0	41.2	37.9	35.6	33.8	31.5	31.4	29.7	28.3	<0.001
Sex (male), %	75.0	83.3	69.1	72.2	78.8	75.0	73.1	70.4	76.5	75.0	72.2	74.6	0.693
Blunt mechanism, %	58.3	63.0	73.5	62.0	59.1	73.8	66.7	67.9	73.5	75.0	68.5	74.6	0.023
Falls, %	40.0	47.1	40.0	49.0	41.0	44.1	48.1	60.7	58.0	58.3	62.5	66.0	<0.001
MVC, %	60.0	41.2	48.0	40.8	46.2	46.7	44.2	25.5	26.0	33.3	27.0	18.0	<0.001

MVC, motor vehicle crashes.

TABLE 4. Patient Characteristics by Cause of Death

Cause of Death	Total	AH	MOF/S/ARDS	TCoM	PM	OT	TBIC	p
n	819	232	15	79	87	43	363	
Age, mean, y	51.2	36.8	49.7	79.5	71.3	45.2	50.2	<0.001
ISS, mean	34.7	47.4	36.5	21.6	14.8	26.2	35.2	<0.001
Admission GCS score, mean	6.1	3.9	11.5	12.1	8.6	6.2	5.3	<0.001
Admission SBP < 90 mm Hg, %	42.4	83.6	13.3	6.3	25.3	46.5	28.7	<0.001
Sex (male), %	74.4	80.6	80.0	63.3	62.1	79.1	74.9	0.004
Blunt mechanism, %	68.1	34.5	80.0	94.9	98.9	60.5	76.9	<0.001
LOS ≥ 24 h, %	42.3	3.0	100.0	83.5	58.6	55.8	50.4	<0.001

seen in TBIC and MOF/S/ARDS causes of death, overall, four of the five strata saw generally decreasing trends. The only increasing trend related to the combined causes of PM/TCoM, which was statistically significant.

DISCUSSION

These analyses confirmed our hypothesis that increases in elderly trauma patients with preexisting comorbidities have altered the distribution of death after trauma. During the 12-year period, mortality caused by trauma combined with significant comorbidities and those related to purely medical causes significantly increased. Death caused by acute hemorrhage and the combined causes of MOF/S/ARDS decreased significantly after the sequential introduction of four major practice guideline changes. Establishing the causal relationship between the adoption of these guidelines and reductions in mortality was beyond the scope of this study. However, these changes were

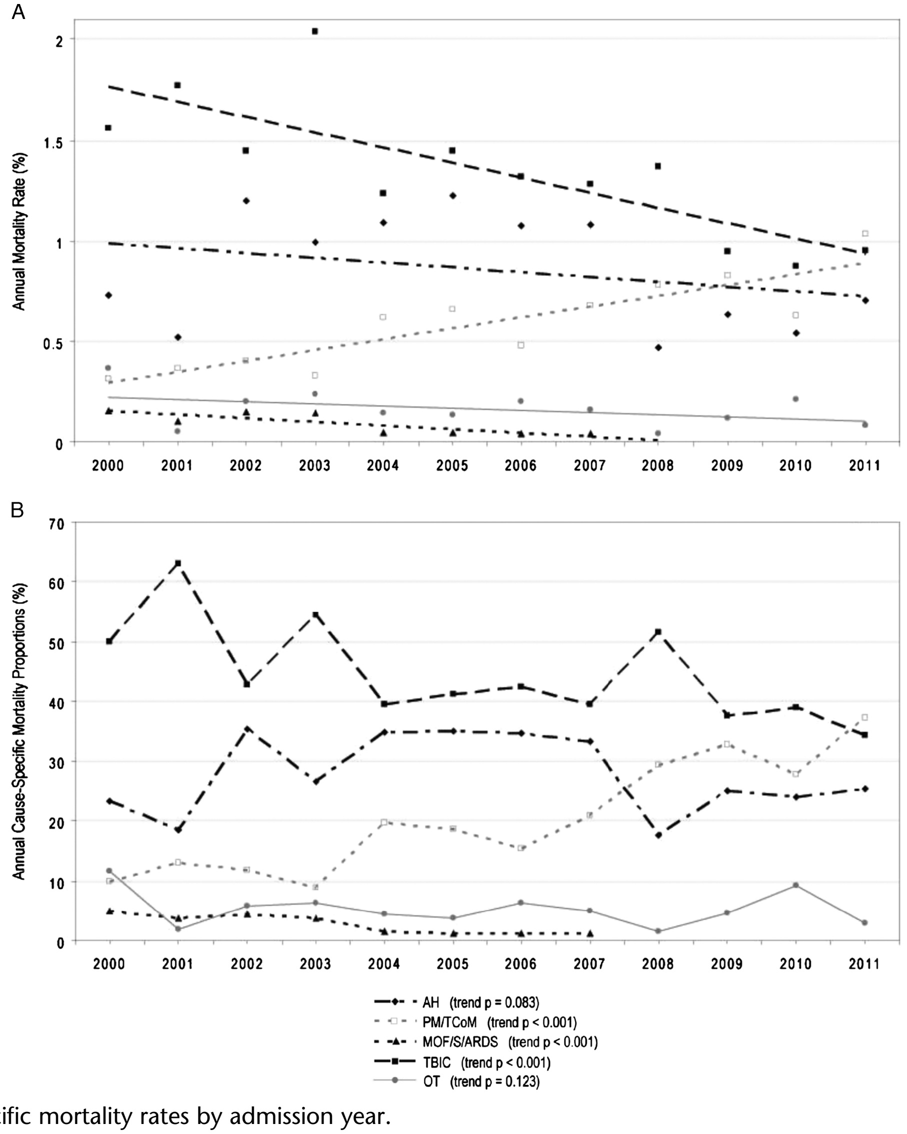

Figure 2. Cause-specific mortality rates by admission year.

implemented during a time when the age and prevalence of severe injuries in our trauma population increased although the rate of hemodynamic instability at admission remained unchanged.

This is the first study to report a significant increase in trauma center deaths caused by age-related preexisting comorbidity, either in conjunction with a traumatic injury or as a sole cause of death. Other data have shown that elderly patients with minor trauma have a significantly higher risk of death compared with their younger counterparts and that preexisting comorbidities negatively impact survival after trauma.[18–22] However, recent analyses of the pattern of death after trauma do not identify the rise in elderly trauma deaths seen in our study. A report of 2000 to 2009 data from 28 Pennsylvania trauma centers showed a significant decline in in-hospital mortality despite an increase in the age of the trauma population and the prevalence of severe injuries.[23] Causes of death were not evaluated. A review of studies published from 1980 to 2008 on the causes of trauma mortality at Level I centers revealed a recent decrease in deaths caused by acute hemorrhage.[3] Rates of other causes of death after trauma (sepsis, multiorgan failure, respiratory failure, and central nervous system injury) were unchanged. A single-center review of trauma mortality from 1997 to 2008 showed an increase in the age of the patient population and a slight increase in deaths caused by an increase in mortality for penetrating injuries.[4] Although predominant causes of death were identified (traumatic brain injury, acute hemorrhage, and multiorgan failure), the analysis was largely limited to associations between specific causes and the mechanism of injury (blunt vs. penetrating), which was unchanged over time.

Three studies evaluating trauma deaths in the San Diego County Trauma System serve as points of reference for the changes identified in our study. A 1989 report reviewed all deaths during a 1-year interval at a Level I trauma center in the recently regionalized county trauma system.[24] Central nervous system trauma was the most common cause of death. Although comorbidities were not evaluated, trauma patients who died later were observed to be older than those who died earlier. A subsequent study analyzed all trauma deaths countywide during a 1-year period.[1] Central nervous system trauma remained the predominant cause of death. However, complications, rather than the direct effects of a primary injury, were responsible for a majority of late deaths. In the third study, deaths in the regionalized system were analyzed during the years 1987 to 1997.[5] During the 11-year interval, mean age of the injured increased, as did falls as a mechanism; associated mortality did not rise. However, an association between mortality and preexisting comorbidities was identified. Given previous reports, our finding of a significant rise in elderly trauma deaths caused by injury in conjunction with comorbidities is a relatively recent development.

Several reasons may explain our observations. Most likely, the decrease in deaths caused by AH and the complete disappearance of deaths caused by MOF/S/ARDS were mitigated by the steady rise in deaths caused by TCoM or PM. It is also possible that the small variation in the overall death rate reflected the stability of the San Diego County Trauma System with fixed catchment area boundaries in effect for more than two decades.

Changes in the causes of death were temporally related to four major innovations incorporated in our practice guidelines. Aggressive monitoring for VTE and the use of mechanical and chemoprophylaxis have been shown to improve outcomes.[9] Before the introduction of our VTE guidelines, we observed two deaths from pulmonary embolism. None was observed subsequent to this practice change. The implementation of lung protective ventilation may have contributed to the reduction of patients dying of MOF/S/ARDS. The impact of this guideline on reducing the incidence of ARDS and improving survival is well established.[11,12,25] The use of fresh frozen plasma from male donors has also been associated with a reduced incidence of TRALI.[7] Although the rate of TRALI is low, the one related death we encountered occurred before our adoption of this innovation.

Multiorgan failure, sepsis, and ARDS were no longer causes of death after we comprehensively adopted damage-control resuscitation in April 2007. Others have described the reduction in ARDS and organ failure associated with this approach.[13–15] A review of both military and civilian reports noted a marked decrease in ARDS and other organ failure in massively transfused patients in whom DCR was used.[13] Another review of the published literature on fluid resuscitation cited the proinflammatory effect of large volumes of crystalloid infusions (our practice before 2007) on patients in shock.[14] Finally, a recent study documented the association of high platelet transfusion ratios with improved survival, adding to the evidence that blood component transfusions improve outcomes in patients with hemorrhagic shock.[15] These innovations may have contributed to the prolonged reduction in all-cause mortality rates in the 10th year of our series.

This study is not without limitations. It is a single-center study, and the findings may not be generalizable to other trauma centers with a different trauma population. We also had a limited number of overall deaths caused by the combined causes of MOF/S/ARDS. The reduction from 5% to 0%, although a statistically significant drop relative to all causes of death, may not be sufficiently powered for us to conclude that it is no longer a factor in trauma deaths. We further noted a coincidence of the adoption of four innovations with reductions in these causes of death. This relationship may not be causative, and we are unable to draw a definitive conclusion in that regard because of the small numbers of deaths brought about by those causes. Finally, patient comorbidity data were not available for the first half of the 12-year study period.

CONCLUSION

In conclusion, we confirm recent changes in the causes of death on our trauma service that seem to be related to an increase in elderly patients with comorbid conditions. Death caused by the complications of comorbid conditions alone or in combination with a survivable injury increased, while death from the complications of injury (or its treatment) significantly decreased. Although we did not demonstrate a causal relationship, decreasing deaths caused by acute hemorrhage and the combined causes of MOF/S/ARDS occurred after the sequential introduction of four major practice guideline changes. Future improvements in trauma outcomes will require concentrating on efforts to improve the in-hospital management of elderly patients' comorbid conditions.

AUTHORSHIP

J.E.K., M.J.S., and J.F.T. designed this study. J.E.K., M.J.S., C.B.S., and J.F.T. conducted the literature search. J.E.K., R.Y.C., M.J.S., and J.F.T. collected the data, which J.E.K. and R.Y.C. analyzed. R.Y.C., M.J.S., and S.R.S., interpreted the data. J.E.K., R.Y.C., M.J.S., and C.B.S. wrote the article. J.E.K. and R.Y.C. prepared the figures and tables. M.J.S. and S.R.S. edited the final paper.

DISCLOSURE

The authors declare no conflicts of interest.

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