Time and place of death from automobile crashes: Research endpoint implications

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BACKGROUND:	Vehicle crashes are a leading cause of US injury and death. Early death, however, has almost entirely been studied in-hospital. The US Department of Transportation Fatality Analysis Reporting System (FARS) database captures both prehospital and in-hospital mortality.
METHODS:	FARS location (prehospital, in-hospital) and time of death were reviewed (1978–2013), and a 2003–2005 subgroup of 55,537 early deaths (i.e., between 5 minutes and 4 hours after injury) was analyzed to quantify risk of death over time.
RESULTS:	There has been an overall decrease in 1978–2013 US vehicle-related deaths (from 3.3 deaths per 100 million vehicle miles traveled to 1.1 and from 22.6 per 100,000 population to 10.4). Snapshots of the death data reveal an overall downward trend of total in-hospital and prehospital deaths. The proportion of hospital deaths decreased by 58%, whereas the proportion of deaths in the prehospital period increased to 56%. Subgroup analysis revealed a rate of mortality risk of 0.4% per minute for the first 30 minutes, 1% per minute for the next 60 minutes, and 0.2% per minute and plateauing thereafter.
CONCLUSIONS:	Analysis of census FARS data of motor vehicle crash-related deaths showed an overall 35% decrease in mortality over a period of 36 years. The disproportionate reduction in in-hospital deaths is perhaps a testament to the effectiveness of trauma centers. However, there is a demonstrable need to focus on prehospital deaths with resuscitative and adjuvant therapy research and trauma system design. Quantifying risk of death over time should help focus emergency medical services, trauma system, and resuscitation goals. (*J Trauma Acute Care Surg.* 2016;81: 420–426. Copyright © 2016 Wolters Kluwer Health, Inc. All rights reserved.)
LEVEL OF EVIDENCE:	Epidemiologic study, level III.
KEY WORDS:	Automatic crash notification; EMS; prehospital death; trauma research endpoints; vehicle crash.

The 40% increase in global deaths due to injury projected to occur between 2002 and 2030 is largely attributed to the increase in vehicle-crash deaths worldwide.[1] Deaths from injuries increased 23% from 1990 to 2010, and in 2010, they were the primary cause of years of life lost.[2] Thus, perhaps the biggest public health opportunity to save millions of lives every year worldwide is by effective systems of injury control and trauma care. Most trauma-related deaths (84%) occur within the first 12 hours of injury,[3] with a median time of 52 minutes.[4] This study thus concentrates on the need to focus on early and prehospital care using vehicle-related crash data as a tracer group.

The National Academy of Sciences' (NAS's) 1966 report, *Accidental Death and Disability: The Neglected Disease of Modern Society*,[5] highlighted the large number of deaths due to motor vehicle crashes and articulated the need for improving (1) emergency medical response and (2) injury diagnosis and treatment by initiating research initiatives. Today, vehicle-related deaths comprise approximately 17% of US trauma deaths. (US Centers for Disease Control and Prevention data show 33,804 of 192,945 injury-related deaths in 2013 as being vehicle-related.)[6] However, the availability of data and the consistency of the epidemiologic subset make them a useful topic for the review of outcomes over the several decades since the generations of surgeons and others have applied themselves to reducing death from injury in the United States. This study was conceived to identify contemporary targets of opportunity to prevent motor vehicle-related deaths. To this end, we examined US Department of Transportation National Highway Traffic Safety Administration (NHTSA) data on US vehicle-related deaths, both prehospital and in-hospital, and specifically looked at the trend of the increasing proportion of deaths in the prehospital period. The objective of this study was to use a comprehensive body of vehicle crash data to illustrate the window of opportunity for reducing deaths on the nation's highways.

METHODS

The data for this analysis were from NHTSA's Fatality Analysis Reporting System (FARS) database. One of two primary NHTSA databases (the other is the National Automotive Sampling System), FARS was established in 1975 to collect data on fatal motor vehicle crashes with the goal of identifying and addressing highway safety issues. FARS collects data from the 50 states; Washington, DC; and Puerto Rico and now contains data on nearly 1.7 million vehicle-related fatalities. In

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2000, FARS began recording geographic information system (GIS) location information for each fatal crash collected in the database. NHTSA publishes GIS location data in FARS on a state-by-state basis.[7] The FARS database has a robust quality control program, and the data are exceptionally comprehensive, with only approximately 1% unable to be classified as prehospital or in-hospital deaths.[8]

FARS inclusion criteria are (1) location of the crash on a public road and (2) death of driver, occupant, or nonmotorist within 30 days of the crash.[9] Data are obtained from police accident reports; death certificates; and coroner, medical examiner, and emergency medical services (EMS) records.[10] The characteristics of each fatal crash are coded using 143 parameters.

This study consisted of two analyses: (1) a review of vehicle-related fatalities between 1978 and 2013 (the years for which NHTSA has prehospital and in-hospital death data) and (2) a subgroup analysis of 2003–2005 data to ascertain risk of death over time. The latter was chosen as a timeframe that was not yet subject to the uneven flux in care caused by changing resuscitative practices and adjuvant therapies (which might confound the analysis) and which thus establishes a stable baseline for future studies. The analyses were limited to early deaths, i.e., patients who died more than 5 minutes and less than 4 hours after injury because preliminary investigation and other studies (discussed below) have suggested that this might be a prime window for preventable death intervention strategies, tactics, and techniques.

RESULTS

In the decades since the mid-1970s, when trauma centers and systems were introduced and implemented across the nation, there have been 1.6 million vehicle-associated deaths.[11] During that time, however, great strides have been made in reducing the numbers of annual deaths. In 1978, there were 50,331 motor vehicle-crash deaths, a number that declined to 32,719 in 2013 (a 35% decrease).[11] As shown in Figure 1, the fatality rate per 100 million vehicle miles traveled has declined 66% (from 3.3 in 1978 to 1.1 in 2013), and the fatality rate per 100,000 population has declined 54% (from 22.6 to 10.4).[11]

Despite this favorable overall trend, the proportion of deaths that occurred before the patient reached a hospital has increased to 56% since 2000. Thus, the proportion of in-hospital deaths declined to 44% (Fig. 2).[12] The actual numbers of deaths are shown in Figure 3.[12]

To explore the relationship of death over time in prehospital vehicle-crash deaths, a subgroup analysis of 55,537 early deaths (within 5 minutes and up to 4 hours) between 2003 and 2005 in the FARS database was undertaken. This analysis showed that early vehicle-related deaths occur at a defined rate with a risk of 0.4% per minute for the first 30 minutes, 1% per minute for the next 60 minutes, and 0.2% per minute and plateauing thereafter. The resultant curve $Y = 908.99e^{-0.013x}$ (Fig. 4) establishes the relationship between time following injury and death in this subgroup.

DISCUSSION

The NAS's 1966 report, *Accidental Death and Disability: The Neglected Disease of Modern Society*,[5] several reports on preventable deaths from hemorrhage,[13–17] and the experience of surgeons and other healthcare providers returning from treating the more than 300,000 combat casualties in Vietnam[18] were the catalyst for applying military medical advances to the civilian trauma setting. The NAS report highlighted the large number of deaths due to motor vehicle crashes and articulated the need for improving both emergency medical response and injury diagnosis and treatment by initiating research initiatives. In 1966, Congress passed the *National Highway Safety Act* (PL 89–564),[19] which, together with the *Emergency Medical Services Systems Act of 1973* (PL 93–154),[20] laid the foundations for today's trauma centers/systems that have been in the process of development and evolution since the early-mid 1970s. In 1990, the *Trauma Care Systems Development Act* (PL 101–590) was passed by Congress (although not reauthorized in 1995), which further boosted trauma system implementation with grants to states.

In the intervening years, advances in resuscitative care and postoperative critical care in-hospital have improved patient

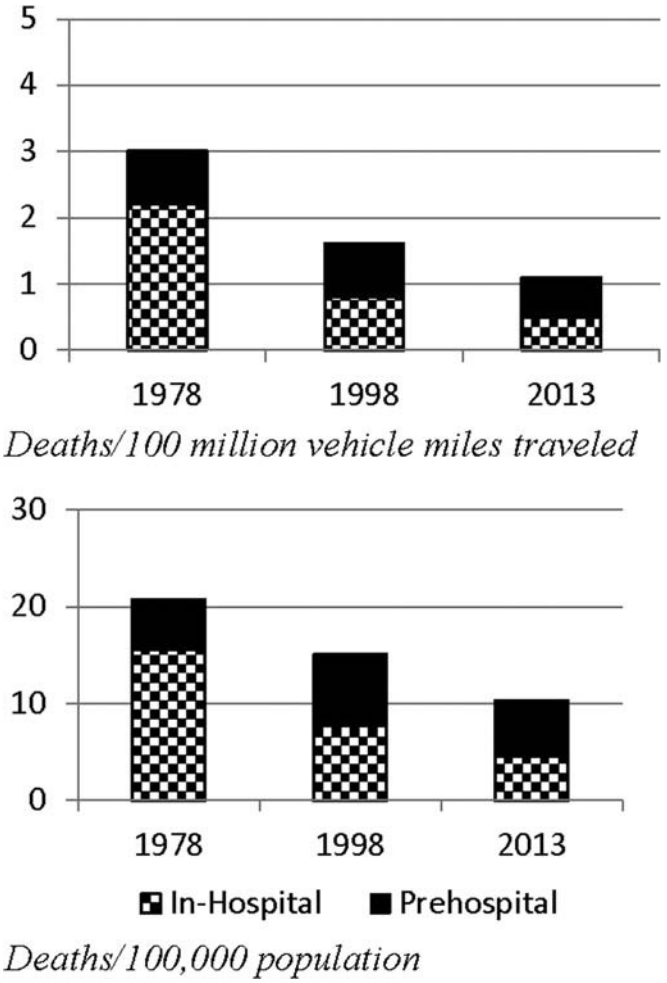

Figure 1. US vehicle-crash deaths: 1978, 1998, 2013. *Top*, Deaths/100 million vehicle miles traveled. *Bottom*: Deaths/100,000 population. Figures do not include data for years in which prehospital/in-hospital death information was unknown (8% in 1978, 1% in 1998).[11]

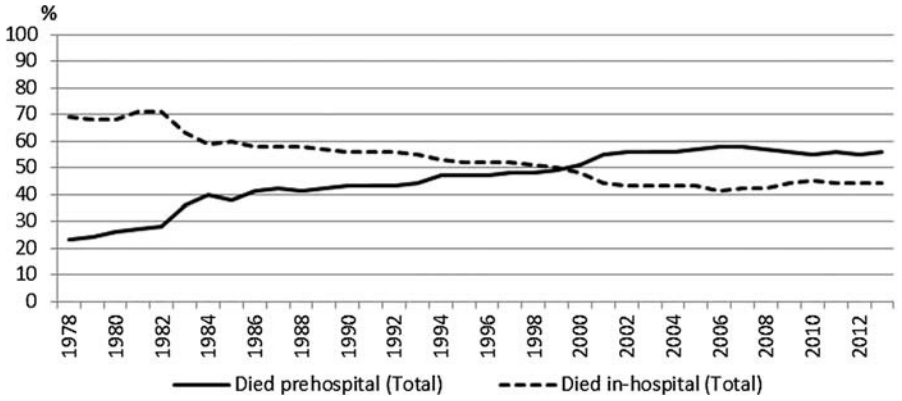

Figure 2. US vehicle-related fatalities, prehospital and in-hospital, 1978–2013, percent.[12]

outcomes and advanced scholarly examination of injury-related death. Thus, it comes as no surprise that in-hospital death rates have decreased. Reductions in in-hospital trauma deaths have been widely documented throughout the world including in countries that have emulated the efforts, commitment, and approaches instantiated in the United States.[21–23] Although nearly all of these studies focused only on hospital admission data, more recent examinations of combat casualty deaths have considered both the prehospital and in-hospital components and have further emphasized that most preventable deaths occur in the prehospital period.[24–26] The current study adds to this literature by providing a census of deaths for a large and consistent body of data on prehospital and in-hospital deaths in the civilian arena over a period of 36 years.

Prehospital Care

Beginning in the mid-1970s, efforts to improve prehospital trauma care were underway. Prehospital initiatives quickly embodied a commitment to trauma care, training of paramedics in resuscitative maneuvers, helicopter transport, and the establishment and widespread propagation of the Pre-Hospital Trauma Life Support (PHTLS) course. Perhaps as a testament to the effectiveness of trauma centers, the FARS data show a rise in proportion of prehospital deaths nationally from 23%[8] in 1978 to 56% in 2013 when compared with in-hospital deaths. This national trend is echoed in 31 states but is reversed in nine and shows approximately equal distribution in 11.[8] (For context, it is important to note that in 1978 FARS was new; there were no airbags, no seatbelt laws, no crashworthiness testing, no Insurance Institute for Highway Safety [IIHS] tests and publicity, i.e., far less vehicle safety.) However, there has also been a substantial increase in vehicles on the road and vehicle miles traveled. With more than half of all crash deaths occurring before arrival at an emergency medical facility (250,000 since 2000 in the United States alone, or nearly 50 people per day), prehospital care and time to definitive care require greater attention.

Examination of rural versus urban vehicle crash mortality rates show associations between increased EMS response time and higher rates of death[27–29] (Fig. 5).[30] This is a worldwide phenomenon. US Census Bureau, World Health Organization, World Bank, and IIHS data on traffic deaths and population density aggregated in a July 2015 article in *The Economist*[31] indicate that the majority of deaths (clustering between 7 and 17 per 100,000 people) occur in areas with 0 to 100 population per square kilometer (e.g., US states such as Louisiana, Mississippi, Montana, and Wyoming) and decline to approximately

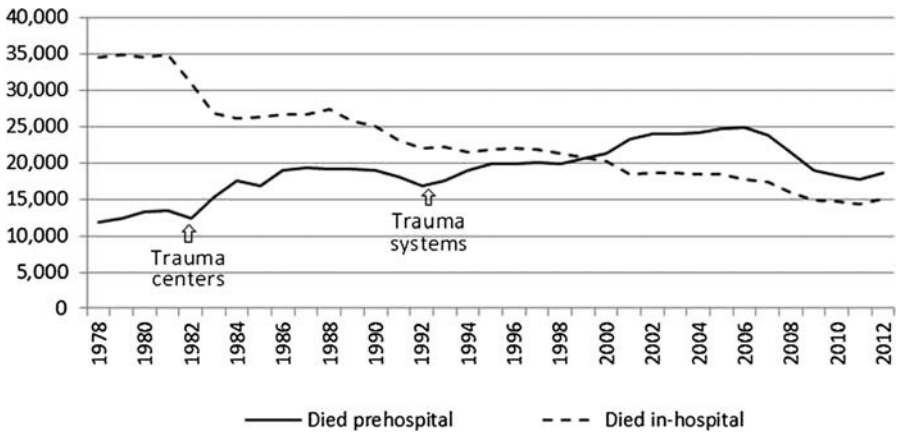

Figure 3. US vehicle-related fatalities, prehospital and in-hospital, 1978–2013, number.[12]

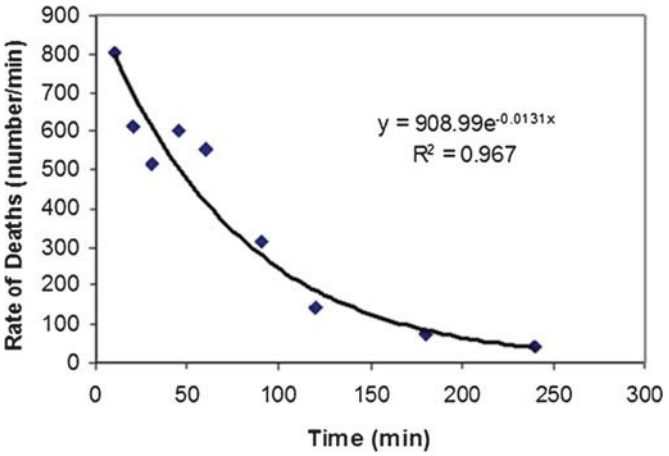

Figure 4. Death versus time: US vehicle-related fatalities 2003–2005.

2.5 per 100,000 people in highly urbanized areas (300–400 people per square kilometer, e.g., in Japan). As a point of reference, the United States as a whole had 10 per 100,000 traffic deaths in 2013.[31] States with large rural populations (including the four mentioned previously) have the highest rate of crash fatalities, in some cases (such as Montana and Mississippi), more than double the national average (Table 1), and a larger proportion (>60%) of prehospital deaths.[32]

Lessons of War

In the same way that the lessons learned from Vietnam found their way into civilian trauma care, the lessons learned in Iraq and Afghanistan are benefitting today's trauma care community, which is now a strong multidisciplinary academic and scholarly force. Medical care of the almost 50,000 injured and 8,300 killed in Operation Iraqi Freedom and Operation Enduring Freedom (Afghanistan)[33] has been meticulously documented and analyzed. A number of these analyses have identified that immediate prehospital (point of wounding) death is the area upon which to focus and that preventable deaths are rare after reaching a surgically staffed medical facility.[25,26] The most recent study (September 2015) documented decreased mortality with reduced prehospital times in Afghanistan.[34]

Cause of Death

Data from both civilian and military settings have identified hemorrhage as the leading cause of early, and sometimes preventable, death following trauma.[25,26,35–37] In a review of combat trauma deaths, Eastridge et al.[26] found that 90% of deaths occur prior to treatment at a medical treatment facility. Overall, 24% of the deaths were potentially preventable, with hemorrhage being the leading cause of death in that population. In the civilian arena, the Resuscitation Outcomes Consortium identified time to death from hemorrhagic shock at approximately 2 hours (compared with 29 hours in a cohort with traumatic brain injury).[37] In the PROMMTT (Prospective Observational Multicenter Major Trauma Transfusion) study of 34,362 trauma admissions, the median time to hemorrhagic death was 2.6 hours (range, 1.7–5.4 hours).[38] Other studies have supported the fact that in patients who are not instantly killed, the median time to death from hemorrhage occurs within 2 hours of injury[39] (the "second peak" of trauma deaths, typically from head injury or hemorrhage, occurs between 30 minutes and 4 hours[40]), thus presenting a target of opportunity for early assessment, resuscitation, hemostatic agent research, and therapeutic advances.

Public Health Model

During the decades since the mid-1970s, a substantial number of factors have reduced the number of deaths from vehicle-related incidents in the United States and Puerto Rico (as shown in Fig. 1). These factors relate to aspects of a public health approach to injury, that is, (1) primary prevention (incident prevention), (2) secondary prevention (mitigation), and (3) tertiary prevention (treatment of the consequences).

Primary prevention efforts have included improvements in road design, speed limits, initiatives against impaired driving, improved driver education, graduated licensing, and improved vehicle design up to and including intelligent systems. Secondary

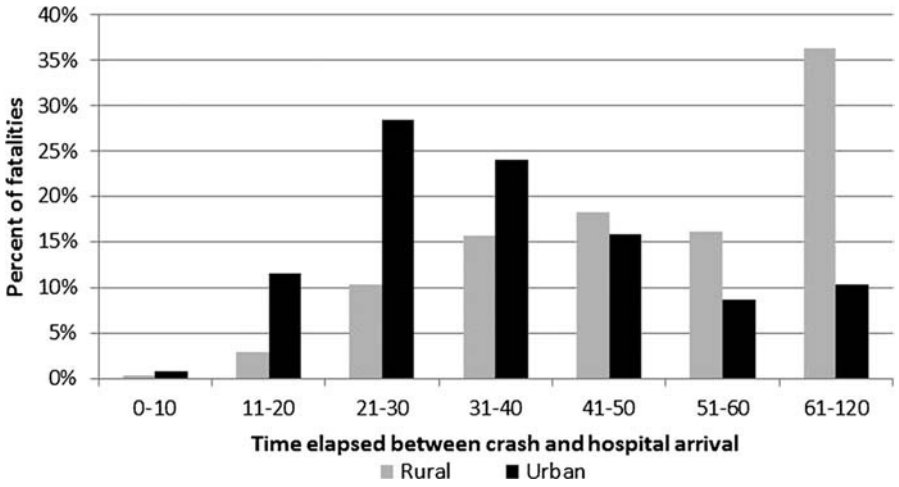

Figure 5. Fatal crashes by EMS response times: Rural versus urban, 2010.[30]

TABLE 1. Crash Fatalities by State, 2013[39]

State	Deaths Per 100,000 Population	Total Killed	% Not Taken for Care (Prehospital Deaths)
Washington, DC	3.09	20	25§
Massachusetts	4.87	326	32§
New Jersey	6.09	542	34§
New York	6.10	1,199	35§
Rhode Island	6.18	65	28§
Washington	6.44	444	66*
Alaska	6.94	51	71*
Minnesota	7.14	387	62*
Hawaii	7.26	102	53†
Utah	7.58	220	53†
Connecticut	7.68	276	45‡
Illinois	7.69	991	43‡
California	7.83	3,000	60*
Maryland	7.84	465	46‡
Oregon	7.96	313	70*
Ohio	8.55	989	53†
Virginia	8.96	740	60*
Nevada	9.39	262	60*
Pennsylvania	9.46	1,208	54†
Wisconsin	9.46	543	62*
Puerto Rico	9.52	344	
Michigan	9.57	947	54†
New Hampshire	10.20	135	58†
Iowa	10.26	317	64*
National	**10.35**	**32,719**	**56†**
Delaware	10.69	99	47‡
Maine	10.92	145	66*
Vermont	11.01	69	49‡
Nebraska	11.29	211	55†
Georgia	11.8	1,179	52†
Indiana	11.92	783	56†
Kansas	12.09	350	63*
Florida	12.31	2,407	53†
Missouri	12.52	757	60*
Texas	12.79	3,382	64*
Arizona	12.81	849	50†
North Carolina	13.09	1,289	55†
Idaho	13.27	214	70*
Kentucky	14.52	638	54†
New Mexico	14.87	310	73*
Wyoming	14.93	87	70*
Louisiana	15.20	703	64*
Tennessee	15.32	995	38§
South Dakota	15.98	135	68*
South Carolina	16.06	767	53†
Arkansas	16.32	483	59†
Oklahoma	17.61	678	60*
Alabama	17.63	852	67*
West Virginia	17.90	332	53†
North Dakota	20.46	148	68*
Mississippi	20.49	613	71*
Montana	22.56	229	64*

*≥60
†50–59%
‡40–49%
§<40%

prevention/mitigation factors include improved crashworthiness, particularly for frontal, offset frontal, side impact, and rollover collisions; and seatbelts, airbags, and motorcycle helmets; and their associated laws mandating use. Both primary and secondary prevention efforts have been required by Congress and bolstered by crash studies initiated by NHTSA, recognized by industry, and significantly performed and propagated by the IIHS and consumer advocates such as *Consumer Reports*. Information dissemination and testing of vehicles continue to improve road safety and change the epidemiologic and mechanistic bases of injuries.

Automated crash notification (ACN) technology is an important tool for reducing time to treatment that is gaining momentum worldwide.[41] General Motors' OnStar system, for example, has 7 million subscribers in the United States, Canada, China, and Mexico and responds to 60,000 crashes per year.[41] Services that can be provided by ACN include identifying the crash location, notifying 911, and providing information that guides EMS, rescue, and triage decisions.[42] ACN and URGENCY software[43] also can indicate the time and distance from the nearest trauma center by ground or air, the need for extrication equipment along with vehicle information such as cut points to speed extrication, and the probability of serious (Abbreviated Injury Scale [AIS] 3+) injury, all within 1 minute of the crash.

Research Focus

The fact that patients with severe injury who do not die immediately after a vehicle crash remain at high risk of early death represents a window of opportunity for intervention. It is now possible to provide more timely and actionable information to EMS and trauma systems so that more optimal care can be delivered to seriously injured patients. Quantifying risk of death over time should help focus EMS, trauma system, and resuscitation goals.

Given the relative increase in prehospital deaths despite improvements in EMS systems over the past few decades, further research efforts should be focused in this area.[44] The rate of risk of death over the first 2 hours indicates that there is an opportunity to explore and develop innovations for implementation in the prehospital setting that have the potential to significantly decrease deaths during this timeframe. Additional analysis is required to determine which factors other than time to treatment are in play and could be impacted by system-level changes. Resuscitation research needs to focus on prehospital and early (<4 hours) endpoints, rather than arbitrary 24-hour or 30-day time periods,[45] which add cost and confound analyses, detracting from more promising therapeutic and system improvements. Given the variation in prehospital deaths by state, further analysis, particularly in states with prehospital death rates less than or equal to in-hospital rates, could provide important information that could be used to help alter this persistent nationwide and global pattern of potentially preventable mortality.

CONCLUSIONS

Analysis of census FARS data of motor vehicle crash–related deaths showed an overall 35% decrease in mortality

over a period of 36 years. The disproportionate reduction in in-hospital deaths is perhaps a testament to the effectiveness of trauma centers. However, the higher proportion of deaths in the prehospital period indicates that there is a demonstrable need to focus on prehospital deaths with resuscitative and adjuvant therapy research and trauma system design. Quantifying risk of death over time should help focus EMS, trauma system, and resuscitation goals.

AUTHORSHIP

H.R.C. and E.J.K. wrote the manuscript. H.R.C., L.V.L., C.E.W., E.J.K., M.M. L., and J.B.H. performed critical revision of the manuscript. L.V.L. and J.B. H. performed data analysis.

DISCLOSURE

The authors declare no conflicts of interest.

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DISCUSSION

Dr. Karen Brasel (Portland, Oregon): Dr. Champion and his co-authors have presented a simple yet elegant review of the epidemiology of trauma deaths from motor vehicle crashes from 1978 to 2013 using the available FARS database.

Although we clamor for well-done, randomized, controlled trials, such studies must have carefully crafted hypotheses and well-designed interventions. These data show the importance of registry or database data as well as carefully done analytic epidemiology for without them we are not able to determine where the weaknesses in our care lie and the areas in which randomized, controlled trials are needed.

Their data demonstrate, essentially, that it is much safer to drive a car than it used to be. Somewhat paradoxically, despite improvements in prehospital care it appears that the proportion of patients dying before transport has increased while there have been many fewer deaths in-hospital.

Perhaps, more importantly, they demonstrate that once the patient is admitted to the hospital the greatest risk of death is within the first two hours.

I have the following questions.

For your analysis looking at the rate of death why did you choose to focus on the time period 2003 to 2005 for those data?

Given the importance of these findings and the significant improvements in resuscitation that have incurred since that time, including balance resuscitation, Factor VIIa and tranexamic acid, wouldn't a more contemporary timeframe have been more informative?

It's very hard to reconcile prior data with the increase in pre-hospital deaths that you show, depending on the denominator. Has the FARS database changed during this time period in terms of data collected, completeness of data collection, or the algorithms used to extrapolate to population level estimates?

Is the lack of linked pre-hospital and hospital data in prior analyses a part of this unanticipated finding?

This analysis demonstrates in a powerful way the importance of epidemiologic study, not only in terms of directing our science but in terms of directing our advocacy.

As an investigator in the Resuscitation Outcomes Consortium, the importance of early death as an endpoint that can be used for large-scale, federally-funded studies is both one that resonates and frustrates.

What can and, more importantly, what should we do specifically as an academic trauma community, both from a scientific and an advocacy standpoint?

I would like to thank the audience for staying to hear this important paper and to thank the AAST for the privilege of discussing it.

Dr. Howard R. Champion (Annapolis, Maryland): Thank you, Dr. Brasel, for your comments. I think you hit on two shortcomings of this paper. One is the 2003 to 2005 analysis. The fact is that we should repeat that later when new approaches to prehospital and adjuvant care are widely in play.

As to the quality of data in this database: when FARS was started, about 8% of the patients were unclassifiable. There has been a noticeable shift in accuracy and completeness of the data and for at least the past 20 years, the data have been at near-census, with fewer than 1% unclassifiable. So we are confident that the past 20-odd years is as good as we can get for this tracer group of motor vehicle crash deaths.

With respect to endpoints: there is no doubt that using endpoints that do not relate to the target pathology adds costs and confounders to our ability to study the effect of various interventions with respect to resuscitative care.

Certainly, we need to focus on policy and work with the FDA to use no later than 24-hour, and probably 6-hour or 4-hour endpoints for resuscitative intervention in structured experimental designs. This would have a huge impact on reducing the costs of these studies.

Finally, this study, at least in part, documents that many of us who are entering our vintage years were able to make a real difference in reducing injury mortality.

To the younger trauma surgeons out there now, I would reiterate Norman McSwain's daily question, "What have you done good for humanity today?" To this, I would add, "How are you going to measure it?" Thank you.