The Effect of Organized Systems of Trauma Care on Motor Vehicle Crash Mortality

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Context Despite calls for wider national implementation of an integrated approach to trauma care, the effectiveness of this approach at a regional or state level remains unproven.

Objective To determine whether implementation of an organized system of trauma care reduces mortality due to motor vehicle crashes.


Setting All 50 US states and the District of Columbia.

Subjects All front-seat passenger vehicle occupants aged 15 to 74 years.

Main Outcome Measures Rates of death due to motor vehicle crashes compared before and after implementation of an organized trauma care system. Estimates are based on within-state comparisons adjusted for national trends in crash mortality.

Results Ten years following initial trauma system implementation, mortality due to traffic crashes began to decline; about 15 years following trauma system implementation, mortality was reduced by 8% (95% confidence interval [CI], 3%-12%) after adjusting for secular trends in crash mortality, age, and the introduction of traffic safety laws. Implementation of primary enforcement of restraint laws and laws deterring drunk driving resulted in reductions in crash mortality of 13% (95% CI, 11%-16%) and 5% (95% CI, 3%-7%), respectively, while relaxation of state speed limits increased mortality by 7% (95% CI, 3%-10%).

Conclusions Our data indicate that implementation of an organized system of trauma care reduces crash mortality. The effect does not appear for 10 years, a finding consistent with the maturation and development of trauma triage protocols, interhospital transfer agreements, organization of trauma centers, and ongoing quality assurance.

Deaths due to MVCs are a useful measure of trauma system effectiveness. For example, injuries occurring as a result of crashes tend to challenge the resources and medical personnel of the institutions caring for such patients due to their complexity and multisystem involvement. Additionally, MVCs frequently occur at sites remote from definitive medical intervention and thus challenge prehospital transportation, triage, and interhospital transfer mechanisms. In this context, we set out to evaluate the effectiveness of organized systems of trauma care in reducing crash mortality by performing a national study of crash deaths, comparing state crash mortality rates before and after implementation of an organized system of trauma care while controlling for secular trends in crash mortality.

METHODS
Identification of Organized Systems of Trauma Care
The primary data source for information regarding regional or state trauma systems was the 1993 Inventory of Systems of Trauma Care.

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Trauma Systems, which provides data on the structural characteristics of trauma systems, both statewide and regionally based, that were operational in 1993. All trauma systems in the inventory have an enabling state statute, regulation, or executive order granting administering organizations the legal authority to develop and enforce trauma system policy. At a minimum, this legal authority involves both the authority to designate trauma centers and the authority to establish triage procedures that allow prehospital personnel to bypass nearer facilities. To update these data, we designed a survey that we sent to all state emergency medical service directors to determine the presence or absence of a trauma system in their state, the nature of the supporting legislation, and the presence and timing of specific components of the trauma system. Additionally, state statutes were reviewed to assess whether there existed any trauma system legislation at the state level that was not apparent either in the Inventory of Trauma Systems or in the results of our survey. We evaluated systems at the state, rather than the regional level, as in most cases, authority for the system rested with state-level organizations and in those states with regionally based systems, the majority of the state population resided within these regions.

We considered the year of first trauma center designation as the start of trauma system implementation within each state. Full implementation of an organized system of trauma care may take several years to develop. Further, the system's effect may not be evident immediately, given that referral practices and triage policies, even if supported by legislation, take time to change. We therefore assessed how crash-related mortality within each state changed over time after the start of trauma system implementation.

MVC Mortality
Data regarding deaths due to MVCs were obtained from the Fatality Analysis Reporting System, which collects data on all fatal MVCs occurring on public roads in the United States in which the death occurred within 30 days of the crash. The analysis was limited to deaths of all front-seat occupants of passenger vehicles aged 15 to 74 years occurring between January 1, 1979, and December 31, 1995. Children were excluded because regionalization of pediatric and adult trauma care may not necessarily develop in parallel, and data on regionalization of pediatric trauma care are not readily available. Fatalities were abstracted by year, age, and state of death. The US Census Bureau provided data on intercensal population estimates by year, state, and age. Our analyses were based on crash mortality rates in the form of deaths per 100,000 person-years, although an analysis based on deaths per vehicle miles driven yielded similar estimates of the effect of trauma systems on crash mortality.

Potential Confounding by Traffic Safety Laws
Our estimates of the effect of trauma system implementation on crash deaths might be in error if we failed to account for other policies that reduce crash mortality. To assess the possible confounding effects of other laws, we selected 3 types of statutes that, according to previous studies, affect deaths due to traffic crashes: (1) primary restraint laws that allow officers to stop vehicles and issue citations if the occupants are not wearing seat belts; (2) secondary restraint laws that allow officers to issue citations for failure to use restraints if the vehicle was stopped for some other reason; (3) administrative license revocation laws, which allow for prompt license suspension if a driver is cited for drunken driving or refuses an alcohol test; and (4) laws that allowed for highway speed limits greater than 55 mph. Data regarding these laws were obtained from the National Safety Council and the National Highway Traffic Safety Administration.

Statistical Analysis
We first carried out a stratified analysis comparing crash mortality rates before and after system implementation in states that had implemented a system during the study period. These state-specific mortality rate ratios (MRRs) were combined using Mantel-Haenszel methods. We then used a regression approach to compare, within each state, crash mortality rates in time periods with an organized system of trauma care to mortality in time periods without such a system, while adjusting for secular trends in crash mortality in all other states and the potential confounding variables described above. The resulting MRR is a pooled estimate of the within-state ratio of mortality rates at any given point in time after system implementation to the mortality rate that would have been expected in those same states had a trauma system not been implemented.

We first used a Poisson regression model to compare the mortality rate in time periods that had an organized system of trauma care to time periods without a system within the same state. To account for trends in crash mortality rates, we included all states in the analysis and modeled time in years using the fractional polynomial method described by Royston and Altman. Briefly, combinations of polynomial terms in the set \((-2, -1, -0.5, 0, 0.5, 1, 2, 3\) were considered, first individually and then in increasingly complex combinations. We used the likelihood ratio test to compare models and systematically selected the best fitting model with the smallest number of terms. Ultimately, 6 terms were used to model trends in mortality and 1 term was used to model time since system implementation. Results were expressed as the MRR for each year after system implementation, compared with expected mortality if there were no system. Pointwise 95% confidence intervals (CIs) were calculated.

To allow for possible overdispersion that might violate the restrictive assumptions of the Poisson distribution, final results were estimated using negative binomial regression. We used variance estimators that allowed for the possibility that observations within each

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state might be correlated.

Analyses were conducted using Stata software (Stata Statistical Software: Release 6.0; College Station, Tex; Stata Corporation, 1999).

RESULTS

Over the 17 years of this study, there were 439,195 deaths due to MVCs. The crash mortality rate for front-seat occupants aged 15 to 74 years was 17.8 per 100,000 person-years in 1979; it decreased to 13.1 per 100,000 person-years in 1995. Adjusting for changes in the age distribution of the population, crash mortality decreased by 22% (95% CI, 21%-23%) over this time interval. From 1979 through 1995, 22 states were identified as having both designated trauma centers and triage policies enforced by legislation (Table 1). In 10 states, the principal organizing and regulating authority was at the state level. Two states had regional systems, wherein a county or series of adjacent counties developed and enforced trauma system policy, while 7 states had regional system development with state enforcement of regulations. In 3 states, the organizational structure was delegated to a private or quasi-private organization given authority by the state. Except for the state of Maryland in which trauma center designation began in 1976, all states began designation of trauma centers from 1979 through 1995.

States implementing a trauma system from 1979 through 1995 experienced a drop in crash mortality from 16.2 to 11.6 deaths per 100,000 person-years. In contrast, states without an organized system of trauma care experienced a decrease in crash mortality from 20.4 per 100,000 person-years in 1979 to 15.4 per 100,000 person-years in 1995. The age-adjusted reduction in crash mortality was 8% (95% CI, 5%-11%) greater over this time interval in states with trauma systems compared to those without. The relative effectiveness of traffic safety laws and trauma systems in contributing to this decline are examined below under “Regression Analysis.” When time periods with a trauma system were compared with time periods without a system within the same state, 18 of 22 states had a statistically significant reduction in crash mortality. Using stratified methods, the pooled MRR was 0.87 (95% CI, 0.86-0.88) in periods with a trauma system compared with time periods without a system. The relative effectiveness of traffic safety laws and trauma systems in contributing to this decline are examined below under “Regression Analysis.” When time periods with a trauma system were compared with time periods without a system within the same state, 18 of 22 states had a statistically significant reduction in crash mortality. Using stratified methods, the pooled MRR was 0.87 (95% CI, 0.86-0.88) in periods with a trauma system compared with earlier periods (Table 1).

Table 1. Crash Mortality Rates in States With Organized Systems of Trauma Care: 1979-1995

<table>
<thead>
<tr>
<th>State</th>
<th>Organizing Authority</th>
<th>Year of First Trauma Center Designation</th>
<th>Crash Mortality Rate per 100,000 Person-years</th>
<th>Mortality Rate Ratio (95% CI)*</th>
</tr>
</thead>
<tbody>
<tr>
<td>California</td>
<td>Regional</td>
<td>1980</td>
<td>16.8</td>
<td>12.2</td>
</tr>
<tr>
<td>Connecticut</td>
<td>State</td>
<td>1995</td>
<td>10.0</td>
<td>7.9</td>
</tr>
<tr>
<td>District of Columbia</td>
<td>State/district</td>
<td>1987</td>
<td>4.0</td>
<td>5.2</td>
</tr>
<tr>
<td>Florida</td>
<td>Regional</td>
<td>1987</td>
<td>16.8</td>
<td>14.4</td>
</tr>
<tr>
<td>Georgia</td>
<td>Regional development, state enforcement</td>
<td>1982</td>
<td>22.7</td>
<td>19.4</td>
</tr>
<tr>
<td>Illinois</td>
<td>Regional development, state enforcement</td>
<td>1988</td>
<td>11.4</td>
<td>10.9</td>
</tr>
<tr>
<td>Maryland†</td>
<td>Private/quasi-private organization given authority by state</td>
<td>1976</td>
<td>. . .</td>
<td>. . .</td>
</tr>
<tr>
<td>Massachusetts</td>
<td>Private/quasi-private organization given authority by state</td>
<td>1980</td>
<td>12.5</td>
<td>7.7</td>
</tr>
<tr>
<td>Missouri</td>
<td>State</td>
<td>1990</td>
<td>18.3</td>
<td>18.6</td>
</tr>
<tr>
<td>Nevada</td>
<td>State</td>
<td>1988</td>
<td>25.4</td>
<td>18.0</td>
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<td>New Jersey</td>
<td>State</td>
<td>1990</td>
<td>9.7</td>
<td>7.1</td>
</tr>
<tr>
<td>New Mexico</td>
<td>Regional development, state enforcement</td>
<td>1985</td>
<td>32.7</td>
<td>25.3</td>
</tr>
<tr>
<td>New York</td>
<td>State</td>
<td>1990</td>
<td>8.5</td>
<td>6.9</td>
</tr>
<tr>
<td>North Carolina</td>
<td>Regional development, state enforcement</td>
<td>1982</td>
<td>21.5</td>
<td>18.0</td>
</tr>
<tr>
<td>Oregon</td>
<td>State</td>
<td>1987</td>
<td>18.2</td>
<td>15.6</td>
</tr>
<tr>
<td>Pennsylvania</td>
<td>Regional/private development, state enforcement</td>
<td>1987</td>
<td>12.5</td>
<td>11.6</td>
</tr>
<tr>
<td>South Carolina</td>
<td>State</td>
<td>1980</td>
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<td>Tennessee</td>
<td>State</td>
<td>1988</td>
<td>19.2</td>
<td>21.8</td>
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<tr>
<td>Utah</td>
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<td>1981</td>
<td>17.6</td>
<td>14.7</td>
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<tr>
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<td>1982</td>
<td>15.5</td>
<td>13.3</td>
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<tr>
<td>Washington</td>
<td>State</td>
<td>1993</td>
<td>14.5</td>
<td>10.2</td>
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<tr>
<td>West Virginia</td>
<td>Regional development, state enforcement</td>
<td>1986</td>
<td>21.7</td>
<td>21.6</td>
</tr>
<tr>
<td>All trauma system states†</td>
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<td>. . .</td>
<td>16.9</td>
<td>14.3</td>
</tr>
</tbody>
</table>

*Ratio of mortality in the years with a trauma system compared with previous years. CI indicates confidence interval. †Maryland had a trauma system throughout the period of analysis. Pooled estimate using Mantel-Haenszel methods.

Regression Analysis

Initiation of an organized system of trauma care appeared to have no beneficial effect on crash mortality with the first 10 years of implementation (Figure). After 10 years, crash mortality decreased compared with what would have been expected within the same states had there been no established system of trauma care. After approximately 13 years, the decrease in mortality was statistically significant. By the 15th year after system implementation, we estimated that the MRR was 0.92 (95% CI, 0.88-0.97) after adjusting for the overall trend in mortality, changes in the age distribution of the population, and the introduction of re-

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When primary or secondary restraint laws were in effect, mortality was reduced compared with time periods without these laws; the reduction appeared to be greater for primary restraint laws (Table 2). Administrative license revocation laws were also associated with reduced mortality. Time periods with a highway speed limit greater than 55 mph had greater crash mortality compared with other time periods. Although all of these laws were associated with mortality, they had little confounding effect on our estimates of the effects of trauma systems on crash mortality. When any or all of these statutes were removed from the regression model, the MRR estimates related to trauma systems were essentially unchanged.

Within a state, crash mortality rates vary from year to year. If a state were to have a period of unusually high rates as part of this expected variation, the state might be stimulated to propose and/or implement an organized system of trauma care. Any subsequent mortality decline could be due partly to the tendency of rates to regress to their mean value. To examine this possibility, we calculated the crash mortality rate in the 3-year period before system implementation and compared these rates with previous years in the same state and adjusted for national mortality trends. Mortality incidence in the 3 years prior to system implementation was little different from that in earlier years: MRR, 1.02 (95% CI, 0.99-1.05).

COMMENT
From 1979 through 1995, 22 states either implemented or already had organized systems of trauma care. About 10 years after system implementation, it appears that mortality due to traffic crashes begins to decline; about 15 years following trauma system implementation, mortality was reduced by 8% (95% CI, 3%-12%). The finding that the effect of trauma systems on mortality may evolve over time is plausible. Designation of the first trauma center, which we chose as the starting date for each system, may have little immediate impact on what actually happens to trauma patients. We believe that over time, trauma center protocols mature, triage policies are implemented, referral patterns and transfer policies change, and ultimately patient outcome improves.

Our estimates are based on the assumption that the time of first trauma center designation represents the beginning of an organized system of care. Although several alternative time-points could have been chosen for the start of trauma system implementation, the year of first trauma center designation was selected for several reasons. First, it was a readily available and discrete point in time that signified a change in the way trauma patients would be treated in the region of interest. It was also the earliest identifiable such point in most states and thus represented the initiation of some form of organized trauma care. We acknowledge that several other components are critical to the success of a trauma system, including the development of prehospital triage criteria, interfacility transfer protocols, and quality assurance. Most of the other trauma system components require the presence of a designated trauma center, emphasizing the importance of this particular component to the overall system.

One limitation of our analysis is that we adjusted our estimates for some laws related to traffic safety, but not all possibly relevant traffic laws. We found, however, that adjustment for restraint laws, administrative license revocation, and speed limit laws resulted in essentially no change in our estimates. While the laws we examined were all independently associated with traffic mortality, they had little association with the implementation of trauma systems and were not important confounders of our estimates. We suspect that most traffic safety laws are instituted with little regard to the establishment of trauma systems and therefore are not likely to be important sources of residual confounding of our estimates. Also, adjusting for secular trends ensures that many other factors not directly measurable (eg, changes in vehicle design, road design, and improvements in medical care) are incorporated into our final estimates.

Our estimate of the reduction in mortality attributable to trauma system implementation is likely to be conservative for several reasons. First, there may have been misclassification of states with and without organized systems of care. For example, our analysis was limited to trauma systems that were backed by legislation in the form of a state statute, regulation, or executive order. However, some regions or states that have relatively well-organized systems without supporting legislation were not considered systems for the purpose of this analysis. Addi-

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tionally, we considered both regional and state-wide systems of trauma care. In states with regional systems, it is unlikely that the entire state population has access to an organized system of trauma care. Finally, approximately half of all crash deaths occur at the scene and thus no trauma system, irrespective of its breadth or quality, can affect the outcome of many of these victims.²⁰

The extent to which trauma system policy is actually enforced in states with trauma systems is unclear. There are data suggesting that even in states with mature trauma systems, compliance with triage criteria for major trauma patients is, at best, approximately 85%.²¹ Data on compliance with triage criteria by state would provide information on whether the process of care of these trauma patients differs following system implementation and would strengthen the causal relationship between system implementation and lower crash mortality. Unfortunately, these data are not available in most states and are even less likely to be available in states prior to system implementation.

Other assessments of the effectiveness of trauma systems have demonstrated variable efficacy depending on the study design. For example, one study reported a greater than 50% reduction in the proportion of deaths deemed potentially preventable prior to and following regional system implementation.²² Although these data suggest a marked and rapid improvement in outcome associated with the implementation of a regional trauma system, the assessment of preventability requires judgments by a panel regarding the appropriateness of care and salvageability. In the study mentioned above and other similar studies, the preventable death fraction is calculated by excluding prehospital deaths and patients dead on arrival, precluding any assessment of prehospital care and/or resuscitation.

More recently, Mullins et al²³ evaluated the outcome of hospitalized patients after organization of trauma care in Oregon over a 6-year period wherein mortality was compared in the preimplementation, implementation, and postimplementation phases. Although there was no mortality benefit in the implementation phase, a 35% reduction in mortality was reported within 2 years after implementation, a finding confirming that the effects of system implementation are not instantaneous.

Our study offers several strengths. By analyzing the nation as a whole, we provide a reasonable estimate of the national impact of trauma system implementation. Further, the wide geographic distribution of the trauma system states precludes there being any specific state or regional distinctions that may affect the results. Finally, we did not exclude prehospital deaths, thus providing a more realistic estimate of the effect of organized trauma care on overall mortality.

Our finding of a noteworthy effect of primary seat belt laws on crash mortality and little effect of secondary restraint laws is consistent with the findings of a recent review of other studies of these laws.¹⁰ Our finding of a modest increase in crash mortality associated with raising the 55 mph highway speed limit is consistent with previous studies of speed limits and crash deaths in the United States.¹²,²⁴ We included deaths on all roads, most of which are not affected by the speed limit change, so it is not surprising that our estimate of the change in mortality was small. The estimate of the effectiveness of administrative license revocation laws on crash mortality is similar to that reported in a previous study of legislation directed toward reducing the rates of alcohol-related crashes.¹³ These data support the relative effectiveness of legislative initiatives focused on primary or secondary prevention strategies to reduce crash mortality.

We conclude that implementation of an organized system of trauma care results in a measurable decrease in crash mortality. The effect does not appear for 10 years, a finding consistent with the progressive implementation of organized systems of trauma care over time.

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REFERENCES


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