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# Association Between Emergency Medical Service Response Time and Motor Vehicle Crash Mortality in the United States

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**IMPORTANCE** Motor vehicle crashes (MVCs) are a leading public health concern. Emergency medical service (EMS) response time is a modifiable, system-level factor with the potential to influence trauma patient survival. The relationship between EMS response time and MVC mortality is unknown.

**OBJECTIVES** To measure the association between EMS response times and MVC mortality at the population level across US counties.

**DESIGN, SETTING, AND STUDY POPULATION** This population-based study included MVC-related deaths in 2268 US counties, representing an estimated population of 239 464 121 people, from January 1, 2013, through December 31, 2015. Data were analyzed from October 1, 2017, through April 30, 2018.

**EXPOSURE** The median EMS response time to MVCs within each county (county response time), derived from data collected by the National Emergency Medical Service Information System.

**MAIN OUTCOMES AND MEASURES** The county rate of MVC-related death, calculated using crash fatality data recorded in the Fatality Analysis Reporting System of the National Highway Traffic Safety Administration.

**RESULTS** During the study period, 2 214 480 ambulance responses to MVCs were identified (median, 229 responses per county [interquartile range (IQR), 73-697 responses per county]) in 2268 US counties. The median county response time was 9 minutes (IQR, 7-11) minutes. Longer response times were significantly associated with higher rates of MVC mortality (≥12 vs <7 minutes; mortality rate ratio, 1.46; 95% CI, 1.32-1.61) after adjusting for measures of rurality, on-scene and transport times, access to trauma resources, and traffic safety laws. This finding was consistent in both rural/wilderness and urban/suburban settings, where a significant proportion of MVC fatalities (population attributable fraction: rural/wilderness, 9.9%; urban/suburban, 14.1%) were associated with prolonged response times (defined by the median value, ≥10 minutes and ≥7 minutes, respectively).

**CONCLUSIONS AND RELEVANCE** Among 2268 US counties, longer EMS response times were associated with higher rates of MVC mortality. A significant proportion of MVC-related deaths were associated with prolonged response times in both rural/wilderness and urban/suburban settings. These findings suggest that trauma system–level efforts to address regional disparities in MVC mortality should evaluate EMS response times as a potential contributor.

Invited Commentary

Supplemental content

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Motor vehicle crashes (MVCs) are a leading cause of death and injury in the United States.[1] Improvements to road infrastructure, vehicle design, and traffic safety legislation have led to a decrease in crash mortality from 15.9 per 100 000 person-years in 1995 to 10.9 per 100 000 person-years in 2015.[2] The implementation of organized trauma systems has further reduced deaths by ensuring that patients with severe injury receive timely access to trauma care.[3,4] However, significant variation in crash mortality persists, with rates varying by an order of magnitude between states from 3 to 25 deaths per 100 000 person-years.[5] The contributing role of modifiable trauma system–level factors in this disparity is unclear.

Emergency medical service (EMS) response time, defined as time elapsed between EMS notification and arrival on scene, is a system-level factor with potential to influence survival. Emergency medical services provide the critical link between injury and definitive care.[6] Early arrival of EMS at the crash scene allows for stabilization of occupants with life-threatening injuries, timely triage, and transport to hospital.[6,7] Conversely, delays could lead to a greater risk of death.

We postulated that a relationship exists between regional EMS response capabilities and crash mortality and that reducing the time to first medical contact in the field might decrease deaths due to road traffic injuries at the system level. Therefore, we measured the association between EMS response times and MVC mortality at the population level across US counties and estimated the number of fatalities that might be prevented if response times were shortened.

### Key Points

**Question** Are regional emergency medical service response time capabilities associated with motor vehicle crash mortality?

**Findings** In this population-based study of 2268 US counties, longer emergency medical service response times were associated with higher rates of motor vehicle crash mortality after adjusting for measures of rurality, emergency medical service on-scene and transport times, access to trauma resources, and traffic safety laws. With use of the population attributable fraction, a significant proportion of motor vehicle crash deaths were found to be associated with prolonged response times in rural/wilderness and urban/suburban settings.

**Meaning** The findings suggest that trauma system–level efforts to address regional disparities in motor vehicle crash mortality should evaluate emergency medical service response times as a potential contributor.

## Methods

### Study Design

This study was a population-based analysis of MVC-related deaths within US counties from January 1, 2013, through December 31, 2015. The specific study objectives were to (1) to measure the association between EMS response time and MVC mortality at the US county level and (2) estimate the proportion of MVC-related deaths associated with prolonged response times. Data were analyzed from October 1, 2017, through April 30, 2018. This project was approved by the Sunnybrook Health Sciences Center research ethics board (Toronto, Ontario, Canada). The data sources used are publicly available and deidentified; informed consent was waived.

### Data Sources

#### Emergency Medical Service Response Time

Data related to ground EMS activations during calendar years 2013 through 2015 were provided by the National Emergency Medical Services Information System (NEMSIS),[8] a federally funded project designed to standardize EMS patient care reporting and facilitate collection of data for assessment of EMS systems of care.[9] As of 2015, NEMSIS collected data related to EMS activations performed by EMS agencies in 2497 of 3144 US counties and county equivalents. We included all ground ambulance responses for possible injury due to MVCs (**Figure 1**). Emergency medical service response times were aggregated at the county level. The exposure was defined as the county median EMS response time (henceforth referred to as county response time), an ecologic measure of regional EMS responsiveness to traffic crashes. Emergency medical service activations with missing response time were excluded (<0.2%). Counties with fewer than 5 EMS responses to MVCs across the 3-year study period were also excluded (4%).

#### Motor Vehicle Crash Mortality Rate

Motor vehicle crash–related deaths were derived from the Fatality Analysis Reporting System of the National Highway Traffic Safety Administration.[10] The Fatality Analysis Reporting System is a population-based registry that collects data related to all MVCs on public roads in the United States that result in at least 1 fatality within 30 days.[11] To reduce the potential for confounding, fatalities were limited to occupants of passenger vehicles. Crashes involving heavy trucks, motorcycles, off-road vehicles, cyclists, or pedestrians were excluded. The US Census Bureau provided intercensal population estimates for each county and year.[12] The primary outcome was the county rate of MVC mortality reported as deaths per 100 000 person-years. To account for demographic differences known to be associated with risk of MVC death,[13,14] county mortality rates were stratified by age (<15, 15-34, 35-64, and ≥65 years) and sex.

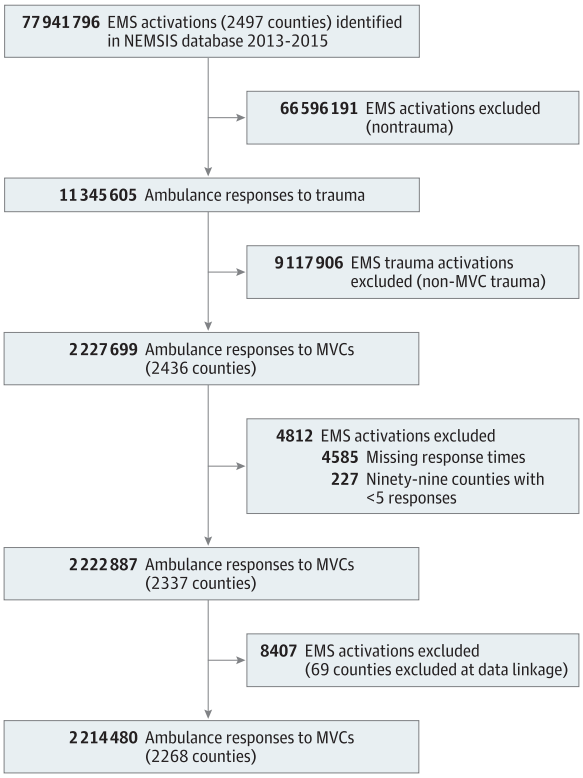
#### Linkage of Emergency Medical Service and Motor Vehicle Crash Mortality Data

The NEMSIS Technical Assistance Center performed linkage of crash mortality and EMS data at the county level using Federal Information Processing Standards (FIPS) codes. County FIPS codes were then replaced using a random identifier to preserve anonymity. Counties where identifiable combinations of data might pose a risk to anonymity were excluded (<3% of counties). The stepwise derivation and structure of the final analytic data set is described in the eMethods in the Supplement.

### Potential Confounders

We considered several factors in addition to population age and sex that might confound the association between EMS re-

Figure 1. Flowchart of Emergency Medical Service (EMS) Activations and Counties Included in the Study




MVC indicates motor vehicle crash; NEMSIS, National Emergency Medical Services Information System.

sponse time and MVC mortality. County rurality was estimated using county population density and rural-urban continuum codes.[15] Population densities were calculated using US census population estimates[12] and grouped into quartiles (<16, 17-42, 43-108, and ≥109 persons/mile$^2$). Rural-urban continuum codes were used to group counties into 4 categories of rurality (urban, suburban, rural, and wilderness) based on population and proximity to metropolitan areas (eTable 1 in the Supplement).

Emergency medical services on-scene and transport times to hospital might also be associated with crash mortality. These time intervals were derived for ambulance responses for which the final destination was a hospital. Median on-scene and transport times were calculated for each county.

Regional differences in EMS response time are also likely to be correlated with access to trauma resources.[16] We accounted for the proximity of trauma centers[17] and helicopter EMS[18,19] to county populations. American College of Surgeons-verified and state-designated level I and II trauma centers were identified from the American College of Surgeons [20] and American Trauma Society[21] databases and geocoded by address using geographic information system (GIS) software. Counties were then categorized by trauma center proximity (within county, adjacent county, or no proximate trauma center) (eFigure 1 in the Supplement).

Access to helicopter EMS was estimated for each county as the proportion of the population within 25-mile flight circles of a helicopter EMS base (corresponding to areas within 15- to 20-minute helicopter EMS response times[22,23]) (eFigure 2 in the Supplement). Helicopter EMS bases were identified in the Atlas & Database of Air Medical Services[24] and geocoded by zip code. The geographic distribution of populations within counties were geocoded using the centroids of census blocks provided by the US Census Bureau.[25]

Finally, state traffic safety laws known to influence the risk of MVC fatality were considered. These laws included the maximum posted speed limits on urban and rural highways and interstates,[26,27] primary enforcement of seat belt laws,[28,29] administrative license revocation for alcohol-impaired driving,[30,31] and legislation prohibiting texting while driving.[32] Traffic safety laws were obtained from the Insurance Institute for Highway Safety[33] and the Governors Highway Safety Administration.[34]

## Statistical Analysis

To assess the generalizability of our results, characteristics of counties included in the study were compared with those of excluded counties. Univariable analyses compared county characteristics across quartiles of county response time. The Wilcoxon rank sum and Kruskal-Wallis tests were used in analysis of continuous variables, and frequencies were compared using the $\chi^2$ test.

A hierarchical negative binomial regression model was used to estimate the risk-adjusted association between county response time and MVC mortality. This model was a generalized linear mixed model with random effects to account for clustering of counties within states.

To estimate the proportion of MVC-related deaths associated with prolonged EMS response times, we used the population attributable fraction.[35-37] The population attributable fraction is defined as the fraction of all cases (in this case, MVC fatalities) in a population that is attributable to a specific exposure (in this case, prolonged response times), assuming a causal relationship. This was estimated using adjusted mortality rate ratios (MRRs) from the hierarchical model using the formula described by Rockhill et al[37] and Miettinen[38]: population attributable fraction = $P_c$ (1 − 1/MRR) × 100%, where $P_c$ is the proportion of MVC fatalities that occurred in counties with prolonged response times (prevalence of the exposure among cases). In this study, the population attributable fraction can be interpreted as the estimated fraction of all MVC fatalities that might have been prevented if all counties achieved response times below the defined threshold.

Owing to geographic and resource constraints, it is unlikely that rural counties would be able to achieve EMS response times comparable to those of urban counties. Therefore, we performed a stratified analysis grouping counties into rural/wilderness and urban/suburban counties using rural-urban continuum codes. The median county response time was calculated separately for rural/wilderness and urban/suburban counties to define the prolonged response time threshold appropriate to each context. The population attrib-

Table 1. Comparison of County Characteristics Across Quartiles of EMS Response Time[a]

| Characteristic | Median EMS Response Time | | | | P Value |
|---|---|---|---|---|---|
| | <7 min (n = 480) | 7-8 min (n = 629) | 9-11 min (n = 656) | ≥12 min (n = 503) | |
| **County Rurality** | | | | | |
| Rural-urban continuum | | | | | |
| Urban | 292 (60.8) | 321 (51.0) | 183 (27.9) | 90 (17.9) | <.001 |
| Suburban | 68 (14.2) | 84 (13.4) | 55 (8.4) | 23 (4.6) | |
| Rural | 102 (21.3) | 179 (28.5) | 293 (44.7) | 156 (31.0) | |
| Wilderness | 18 (3.8) | 45 (7.2) | 125 (19.1) | 234 (46.5) | |
| Population density, people/mile$^2$ | | | | | |
| <16 | 31 (6.5) | 53 (8.4) | 158 (24.1) | 278 (55.3) | <.001 |
| 17-42 | 67 (14.0) | 136 (21.6) | 236 (36.0) | 136 (27.0) | |
| 43-08 | 117 (24.4) | 174 (27.7) | 191 (29.1) | 68 (13.5) | |
| ≥109 | 265 (55.2) | 266 (42.3) | 71 (10.8) | 21 (4.2) | |
| **EMS Time intervals, Median (IQR), min** | | | | | |
| On-scene time | 16 (14-17) | 17 (15-19) | 17 (15-20) | 19 (16-22) | <.001 |
| Transport time | 11 (9-14) | 13 (11-18) | 17 (13-22) | 23 (15-32) | <.001 |
| **Measures of Access to Definitive Care** | | | | | |
| Proximity to level I or II trauma center | | | | | |
| Within county | 132 (27.5) | 95 (15.1) | 17 (2.6) | 28 (5.6) | <.001 |
| Adjacent county | 160 (33.3) | 259 (41.2) | 252 (38.4) | 154 (30.6) | |
| No proximate trauma center | 188 (39.2) | 275 (43.7) | 387 (59.0) | 321 (63.8) | |
| Population ≤25 miles from HEMS base, median (IQR), % | 97 (37-100) | 85 (20-100) | 52 (1-93) | 13 (0-71) | <.001 |
| **State Traffic Safety Laws** | | | | | |
| Maximum speed limit >65 mph | | | | | |
| Urban highways and interstates | 180 (37.5) | 288 (45.8) | 289 (44.1) | 230 (45.7) | .02 |
| Rural highways and interstates | 409 (85.2) | 556 (88.4) | 599 (91.3) | 460 (91.5) | .003 |
| Primary enforcement of seat belt laws | 373 (77.7) | 482 (76.6) | 460 (70.1) | 260 (51.7) | <.001 |
| Administrative license suspension | 407 (84.8) | 521 (82.8) | 553 (84.3) | 403 (80.1) | .18 |
| Text messaging ban | 436 (90.8) | 560 (89.0) | 576 (87.8) | 400 (79.5) | <.001 |
| **Population and MVC Mortality** | | | | | |
| Estimated population[b] | 123 029 515 | 77 014 040 | 24 786 836 | 14 633 730 | NA |
| MVC-related deaths[b] | 6031 | 5233 | 3097 | 1737 | NA |
| MVC mortality rate, deaths/100 000 person-years | 4.9 | 6.8 | 12.5 | 11.9 | NA |
| Crude mortality rate ratio, 95% CI[c] | 1 [Reference] | 1.27 (1.12-1.44) | 1.63 (1.45-1.84) | 1.95 (1.72-2.22) | <.001 |

Abbreviations: EMS, emergency medical service; HEMS, helicopter emergency medical service; IQR, interquartile range; MVC, motor vehicle crash; NA, not applicable.

[a] Data are presented as number (percentage) of counties unless otherwise indicated.

[b] Population estimates and MVC-related deaths shown are from the most recent study year (2015).

[c] Estimated using empty negative binomial model.

utable fraction was then estimated for rural/wilderness and urban/suburban counties using these benchmarks.

Geospatial analyses deriving variables for proximity of trauma centers and helicopter EMS to county populations were performed using Esri ArcMap GIS software, version 10.5 (Esri). Statistical analyses were performed using SAS software, version 9.4 (SAS Institute Inc).

## Results

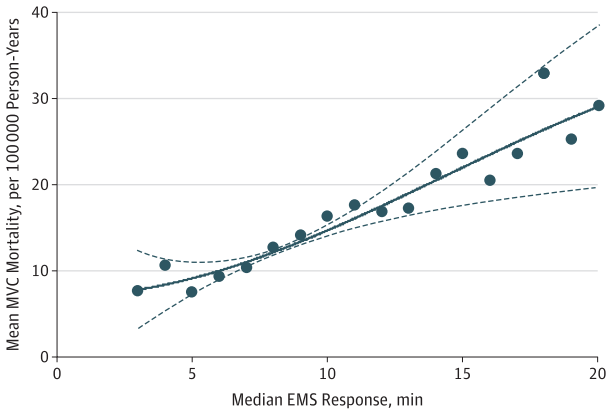
During 2013 through 2015, there were 77 941 796 EMS activations in 2497 US counties (Figure 1). We identified 2 214 480 ambulance responses to MVCs that met inclusion criteria in 2268 counties (72% of all US counties). The median number of ambulance responses to MVCs for each county was 229 responses (interquartile range [IQR], 73-697 responses).

Counties included were from 49 US states (including the District of Columbia) and accounted for an estimated 239 464 121 persons (75% of the total US population). Densely populated urban areas with greater access to trauma center care were overrepresented among the counties analyzed (eTable 2 in the Supplement).

**Table 1** compares the characteristics of counties across quartiles of county response time. The median county response time was 9 minutes (IQR, 7-11 minutes). Counties with longer response times were more often rural, had longer on-scene and transport times, had less access to level I or II trauma centers, and had lower helicopter EMS availability. Conversely, counties with shorter response times were associated with greater presence of protective state traffic safety laws.

The MVC mortality rate was significantly higher in counties with longer response times. In counties with response times of 12 minutes or greater, the mortality rate was 11.9 per 100 000

Figure 2. Crude Association Between County Median Emergency Medical Service (EMS) Response Time and County Rate of Motor Vehicle Crash (MVC) Mortality




Blue circles represent the mean county MVC mortality rate associated with each incremental increase in county response time. Lines represent the best-fit polynomial to mean MVC mortality rates (solid line) and 95% CIs (dashed lines) associated with increasing county response times.

person-years; counties with response times of less than 7 minutes had a mortality rate of 4.9 per 100 000 person-years (unadjusted MRR, 1.95; 95% CI, 1.72-2.22). A near-linear association was observed between county response time and MVC mortality rate (**Figure 2**).

## Hierarchical Negative Binomial Model

**Table 2** shows the results of our hierarchical negative binomial model for county MVC mortality. After adjusting for potential confounders, longer county response times were associated with higher rates of MVC-related death (county response time, ≥12 vs <7 minutes; MRR, 1.46; 95% CI, 1.32-1.61). Crash mortality was highest among males aged 15 to 34 years and in rural counties with low population density. The presence of a level I or II trauma center within a county was associated with lower mortality (MRR, 0.65; 95% CI, 0.59-0.72), whereas higher maximum speed limits on rural highways and interstates were associated with greater mortality. On-scene times, transport times, access to helicopter EMS, and other traffic safety laws were not significantly associated with MVC mortality.

## MVC Deaths Associated With Prolonged EMS Response Times

We estimated the population attributable fraction of MVC deaths associated with prolonged response times in rural/wilderness and urban/suburban counties (eTable 3 in the Supplement). The median county response time among rural/wilderness counties was 10 minutes (IQR, 8-12 minutes) compared with 7 minutes (IQR, 6-9 minutes) among urban/suburban counties. In rural/wilderness counties, the proportion of crash fatalities associated with EMS response times of 10 minutes or longer was 9.9% (95% CI, 4.8%-14.1%), representing approximately 333 of 3363 passenger vehicle deaths. In urban or suburban counties, the proportion of crash fatalities associated with EMS response times of 7 minutes or longer was 14.1% (95% CI, 11.5%-16.4%), representing approximately 1796 of 12 735 passenger vehicle deaths. Taken together, an estimated 2129 passenger vehicle deaths per year (13.2% of all crash fatalities within the 2268 counties evaluated) might have been prevented if county response times were shorter than the specified benchmarks in rural/wilderness (10 minutes) and urban/suburban (7 minutes) areas.

Table 2. Hierarchical Negative Binomial Model for County MVC Mortality

| Parameter | Mortality Rate Ratio (95% CI) | *P* Value |
|---|---|---|
| **County EMS Response Time** | | |
| Median EMS response time, min | | |
| <7 | 1 [Reference] | <.001 |
| 7-8 | 1.24 (1.15-1.34) | |
| 9-11 | 1.33 (1.23-1.44) | |
| ≥12 | 1.46 (1.32-1.61) | |
| **Population Demographic Group** | | |
| Male sex | 1.59 (1.52-1.6) | <.001 |
| Age, y | | |
| <15 | 1 [Reference] | <.001 |
| 15-34 | 7.39 (6.88-7.94) | |
| 35-64 | 4.39 (4.08-4.71) | |
| ≥65 | 5.71 (5.31-6.14) | |
| **County Rurality** | | |
| Rural-urban continuum | | |
| Urban | 1 [Reference] | .002 |
| Suburban | 1.03 (0.94-1.13) | |
| Rural | 1.18 (1.09-1.27) | |
| Wilderness | 1.26 (1.14-1.40) | |
| Population density, people/mile$^2$ | | |
| <16 | 1.90 (1.66-2.18) | <.001 |
| 17-42 | 1.46 (1.32-1.62) | |
| 43-108 | 1.34 (1.23-1.45) | |
| ≥109 | 1 [Reference] | |
| **EMS Time Intervals** | | |
| On-scene time (per 2-min increase) | 1.01 (1.00-1.02) | .23 |
| Transport time (per 5-min increase) | 1.01 (0.99-1.02) | .27 |
| **Measures of Access to Care** | | |
| Proximity to level I or II trauma center | | |
| Within county | 0.65 (0.59-0.72) | <.001 |
| Adjacent county | 0.98 (0.92-1.04) | |
| No proximate trauma center | 1 [Reference] | |
| Population ≤25 miles of HEMS base (per 10% increase) | 1.00 (1.00-1.01) | .27 |
| **Traffic Safety Laws** | | |
| Maximum speed limit >65 mph | | |
| Urban highways and interstates | 1.12 (0.96-1.32) | .14 |
| Rural highways and interstates | 1.69 (1.32-2.15) | <.001 |
| Primary enforcement of seat belt laws | 0.88 (0.76-1.02) | .09 |
| Administrative license suspension | 0.86 (0.68-1.08) | .20 |
| Text messaging ban | 0.99 (0.84-1.16) | .91 |

Abbreviations: EMS, emergency medical service; HEMS, helicopter emergency medical service; MVC, motor vehicle crash.

## Discussion

In this population-based analysis of 2268 US counties, longer EMS response times were associated with higher rates of MVC mortality after accounting for measures of rurality, on-scene and transport times, access to trauma resources, and traffic safety laws. This finding was consistent in both rural/wilderness and urban/suburban settings, where a significant proportion of crash fatalities (9.9% and 14.1%, respectively) were associated with prolonged county response times.

These data have important implications for trauma system design and health policy because they suggest that efforts to address regional disparities in MVC mortality should evaluate EMS response times as a potential contributor. That ensuring short EMS response times could save lives seems intuitive. Severe trauma is a time-dependent condition. Prompt arrival of first responders at the scene of a crash provides the greatest opportunity for early stabilization of occupants with life-threatening injuries, timely triage, and mobilization of the broader trauma system to achieve disposition to definitive trauma care.[7] Conversely, delays may confer a greater risk of death among those in need of urgent medical attention. Thus, regional systems in which delays are more common would exhibit higher rates of crash mortality after accounting for other regional differences.

It is important to place the results of this study in context with the current debate surrounding use of response time as an EMS performance measure. To date, there has been scarce evidence that response times influence trauma-related mortality.[39] Studies that previously examined response time intervals were hindered by a lack of risk adjustment[40,41] or were not designed to make system-level recommendations.[42] Furthermore, a greater emphasis on speed has the potential to put the safety of first responders at risk.[7] For these reasons, opinion has moved away from the use of response time standards as performance indicators.

The present study adds to this discussion by showing, for the first time to our knowledge, that EMS response times may be associated with outcomes at the regional trauma-system level. These findings do not necessarily imply that EMS should simply drive faster, but rather that trauma systems should be organized to achieve a quick response to MVCs. Approaches to shortening response time intervals include ensuring adequate numbers[43] and optimizing the distribution of first-responding units in a dynamic and predictive fashion.[44] In regions where geographic and resource constraints are especially limiting, improvements to on-board telematics systems that predict the risk of severe injury may serve to better triage deployment.[45] Although these approaches can be costly, our results suggest that such strategies may yield a public health benefit, particularly where delays in EMS response are common. Studies of cost-effectiveness are required in this area.

On-scene and transport times were not significantly associated with crash mortality. This observation is notable because counties with longer EMS response times also had longer on-scene and transport times, reflecting differences in crash characteristics, EMS practices, and greater travel distances in rural areas. The finding that only EMS response times were significantly associated with mortality after accounting for other regional differences suggests that early medical contact with prehospital personnel is uniquely important to MVC occupant survival at the trauma-system level. Further research is needed to clarify what additional EMS structures and processes of care, such as the level of first-responding unit, provider training, or prehospital interventions, might contribute to the observed mortality benefit of early EMS arrival.

Greater access to trauma center care was associated with lower MVC mortality. Counties with level I or II trauma centers had crash mortality rates 35% lower than those with no nearby trauma center, providing further evidence that trauma centers are associated with reduced risk of injury-related death.[17,46] Conversely, state laws allowing higher speed limits were associated with greater mortality, reaffirming the dominant role of speed in the epidemiology of fatal road traffic crashes.[26,27]

Contrary to previous reports,[4,28-31] primary enforcement of seat belt and administrative license revocation laws were not significantly associated with MVC mortality. These findings likely reflect the updated era in which the data were derived. During 2013 through 2015, seat belt use in the United States surpassed 86%[47] and all states had enforced the blood alcohol content limit of 0.08%.[33] Therefore, although seat belt and alcohol-impaired driving laws prevent traffic deaths, the measurable effect is likely diminished compared with previous periods.

### Limitations

This study has several important limitations. First, there is potential for residual confounding due to regional differences in road traffic crash characteristics. Crash characteristics might confound the relationship between EMS response time and mortality if vehicle occupants in counties with longer response times are more likely to experience forces leading to greater injury severity. As a consequence, a greater proportion of on-scene deaths (including those not modifiable by post-crash interventions) would be observed in regions with longer response times. However, we accounted for several variables that are correlated with crash characteristics, including measures of rurality,[48] on-scene time (prolonged with extrication),[49] and traffic safety laws (particularly those related to speed). Confounding attributable to other processes of care, such as EMS notification, the quality of medical care delivered, and patterns of interfacility transfer, was also mitigated through adjustment for rurality and regional differences in access to trauma resources (trauma centers and helicopter EMS). Second, the 2268 of 3144 US counties included in our analyses were overrepresentative of densely populated urban areas with greater access to trauma center care. However, that a substantial majority of US counties (and population) were included, representing the full spectrum of rurality and resources, is a compensating strength of the study. Third, it is difficult to confirm the completeness of the EMS activations collected by NEMSIS. However, NEMSIS captured

an average of 26 million EMS activations annually during the study period (74% of an estimated 35 million nationally[50]). Therefore, it is reasonable to infer that the data from which our exposure variable was derived were comprehensive for the 72% of US counties included. Finally, the exposure variable itself (median EMS response time) was an ecologic measure of regional EMS response capabilities. Therefore, caution should be taken in making inferences at the individual level from our results (ecologic fallacy).[51] However, individual-level effects were not a concern within the stated objectives of the study, which were to ascertain county-level effects relevant to trauma system design and broader health policy.

## Conclusions

Among 2268 US counties, longer EMS response times were associated with higher rates of MVC mortality. A significant proportion of MVC-related deaths were associated with prolonged response times in both rural/wilderness and urban/suburban settings. These findings suggest that trauma system–level efforts to address regional disparities in MVC mortality should evaluate EMS response time as a potential contributor. Further work is needed to identify other prehospital structures and processes of care that might contribute to regional disparities in trauma outcomes.


### ARTICLE INFORMATION

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**Author Contributions:** Dr Byrne had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis
*Concept and design:* Byrne, Nathens.
*Acquisition, analysis, or interpretation of data:* All authors.
*Drafting of the manuscript:* Byrne, Nathens.
*Critical revision of the manuscript for important intellectual content:* Mann, Dai, Mason, Karanicolas, Rizoli.
*Statistical analysis:* Byrne, Mann, Dai, Mason.
*Administrative, technical, or material support:* Mann, Mason, Nathens.
*Supervision:* Nathens.

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### REFERENCES


1. Centers for Disease Control and Prevention. Injury prevention and control. 2015. https://www.cdc.gov/injury/wisqars/facts.html. Accessed February 20, 2018.

2. National Highway Traffic Safety Administration. FARS annual crash statistics. 2017. https://www.nhtsa.gov/research-data/fatality-analysis-reporting-system-fars. Accessed February 20, 2018.

3. Nathens AB, Jurkovich GJ, Rivara FP, Maier RV. Effectiveness of state trauma systems in reducing injury-related mortality: a national evaluation. *J Trauma*. 2000;48(1):25-30. doi:10.1097/00005373-200001000-00005

4. Nathens AB, Jurkovich GJ, Cummings P, Rivara FP, Maier RV. The effect of organized systems of trauma care on motor vehicle crash mortality. *JAMA*. 2000;283(15):1990-1994. doi:10.1001/jama.283.15.1990

5. Insurance Institute for Highway Safety Highway Loss Data Institute. General statistics. 2015. https://www.iihs.org/iihs/topics/t/general-statistics/fatalityfacts/state-by-state-overview. Accessed February 20, 2018

6. National Academies of Sciences, Engineering, and Medicine. *Medicine. A National Trauma Care System: Integrating Military and Civilian Trauma Systems to Achieve Zero Preventable Deaths After Injury*. Washington, DC: The National Academies Press; 2016.

7. Brown J, Sajankila N, Claridge JA. Prehospital assessment of trauma. *Surg Clin North Am*. 2017;97(5):961-983. doi:10.1016/j.suc.2017.06.007

8. National EMS Information System website. 2017. https://nemsis.org. Accessed Feburary 20, 2018.

9. Mann NC, Kane L, Dai M, Jacobson K. Description of the 2012 NEMSIS public-release research dataset. *Prehosp Emerg Care*. 2015;19(2):232-240. Published online October 7, 2014. doi:10.3109/10903127.2014.959219

10. National Highway Traffic Safety Administration. Fatality Analysis Reporting System (FARS) encyclopedia. 2017. https://www-fars.nhtsa.dot.gov/Main/index.aspx. Accessed February 20, 2018.

11. National Highway Traffic Safety Administration. FARS analytical user's manual. 2017. https://crashstats.nhtsa.dot.gov/Api/Public/ViewPublication/812602. Accessed February 20, 2018.

12. US Census Bureau. Population and housing unit estimates. 2017. https://www.census.gov/programs-surveys/popest/data/data-sets.html. Accessed February 20, 2018.

13. World Health Organization. Road traffic injuries. 2018 http://www.who.int/en/news-room/fact-sheets/detail/road-traffic-injuries.Accessed February 20, 2018.

14. Tavris DR, Kuhn EM, Layde PM. Age and gender patterns in motor vehicle crash injuries: importance of type of crash and occupant role. *Accid Anal Prev*. 2001;33(2):167-172. doi:10.1016/S0001-4575(00)00027-0

15. US Department of Agriculture. Rural-urban continuum codes. 2016. https://www.ers.usda.gov/data-products/rural-urban-continuum-codes/. Accessed February 20, 2018.

16. Branas CC, MacKenzie EJ, Williams JC, et al. Access to trauma centers in the United States. *JAMA*. 2005;293(21):2626-2633. doi:10.1001/jama.293.21.2626

17. Rutledge R, Fakhry SM, Meyer A, Sheldon GF, Baker CC. An analysis of the association of trauma centers with per capita hospitalizations and death rates from injury. *Ann Surg*. 1993;218(4):512-521. doi:10.1097/00000658-199310000-00011

18. Rhinehart ZJ, Guyette FX, Sperry JL, et al. The association between air ambulance distribution and trauma mortality. *Ann Surg*. 2013;257(6):1147-1153. doi:10.1097/SLA.0b013e31827ee6b0

19. Galvagno SM Jr, Haut ER, Zafar SN, et al. Association between helicopter vs ground emergency medical services and survival for adults with major trauma. *JAMA*. 2012;307(15):1602-1610. doi:10.1001/jama.2012.467

20. American College of Surgeons. Searching for verified trauma centers. 2017. https://www.facs.org/search/trauma-centers. Accessed February 20, 2018.

21. American Trauma Society. Find your local trauma center. 2017. https://www.amtrauma.org/?page=findtraumacenter. Accessed February 20, 2018.

22. The Atlas and Database of Air Medical Services (ADAMS). Air medical civilian fleet by rotor wing make/model. 2014. http://www.adamsairmed.org/pubs/rw_make_model_in_ADAMS_multi_year.pdf. Accessed February 20, 2018.

23. The Atlas and Database of Air Medical Services (ADAMS). National & state overview of air medical coverage in 2016. 2016. http://www.adamsairmed.org/pubs/ADAMS_Intro.pdf. Accessed February 20, 2018.

**24**. ADAMS annual public atlas. 2018. http://www.adamsairmed.org/public_site.html. Accessed February 20, 2018.

**25**. United States Census Bureau. TIGER/Line with selected demographic and economic data. 2017. https://www.census.gov/geo/maps-data/data/tiger-data.html. Accessed February 20, 2018.

**26**. Gallaher MM, Sewell CM, Flint S, et al. Effects of the 65-mph speed limit on rural interstate fatalities in New Mexico. *JAMA*. 1989;262(16):2243-2245. doi:10.1001/jama.1989.03430160065031

**27**. Wagenaar AC, Streff FM, Schultz RH. Effects of the 65 mph speed limit on injury morbidity and mortality. *Accid Anal Prev*. 1990;22(6):571-585. doi:10.1016/0001-4575(90)90029-K

**28**. Robertson LS. Estimates of motor vehicle seat belt effectiveness and use: implications for occupant crash protection. *Am J Public Health*. 1976;66(9):859-864. doi:10.2105/AJPH.66.9.859

**29**. Rivara FP, Thompson DC, Cummings P. Effectiveness of primary and secondary enforced seat belt laws. *Am J Prev Med*. 1999;16(1)(suppl):30-39. doi:10.1016/S0749-3797(98)00113-5

**30**. Zador PL, Lund AK, Fields M, Weinberg K. Fatal crash involvement and laws against alcohol-impaired driving. *J Public Health Policy*. 1989;10(4):467-485. doi:10.2307/3342519

**31**. Yao J, Johnson MB, Tippetts S. Enforcement uniquely predicts reductions in alcohol-impaired crash fatalities. *Addiction*. 2016;111(3):448-453. doi:10.1111/add.13198

**32**. Klauer SG, Guo F, Simons-Morton BG, Ouimet MC, Lee SE, Dingus TA. Distracted driving and risk of road crashes among novice and experienced drivers. *N Engl J Med*. 2014;370(1):54-59. doi:10.1056/NEJMsa1204142

**33**. Safety IIfH. Highway safety topics. 2017. http://www.iihs.org/iihs/topics#statelaws. Accessed Feburary 20, 2018.

**34**. Governors Highway Safety Association. State laws by issue. 2017. https://www.ghsa.org/state-laws/issues. Accessed February 20, 2018.

**35**. World Health Organization. Metrics: population attributable fraction (PAF). 2017. http://www.who.int/healthinfo/global_burden_disease/metrics_paf/en/. Accessed February 20, 2018.

**36**. Mansournia MA, Altman DG. Population attributable fraction. *BMJ*. 2018;360:k757. doi:10.1136/bmj.k757

**37**. Rockhill B, Newman B, Weinberg C. Use and misuse of population attributable fractions. *Am J Public Health*. 1998;88(1):15-19. doi:10.2105/AJPH.88.1.15

**38**. Miettinen OS. Proportion of disease caused or prevented by a given exposure, trait or intervention. *Am J Epidemiol*. 1974;99(5):325-332. doi:10.1093/oxfordjournals.aje.a121617

**39**. Harmsen AM, Giannakopoulos GF, Moerbeek PR, Jansma EP, Bonjer HJ, Bloemers FW. The influence of prehospital time on trauma patients outcome: a systematic review. *Injury*. 2015;46(4):602-609. doi:10.1016/j.injury.2015.01.008

**40**. Gonzalez RP, Cummings G, Mulekar M, Rodning CB. Increased mortality in rural vehicular trauma: identifying contributing factors through data linkage. *J Trauma*. 2006;61(2):404-409. doi:10.1097/01.ta.0000229816.16305.94

**41**. Feero S, Hedges JR, Simmons E, Irwin L. Does out-of-hospital EMS time affect trauma survival? *Am J Emerg Med*. 1995;13(2):133-135. doi:10.1016/0735-6757(95)90078-0

**42**. Newgard CD, Schmicker RH, Hedges JR, et al; Resuscitation Outcomes Consortium Investigators. Emergency medical services intervals and survival in trauma: assessment of the "golden hour" in a North American prospective cohort. *Ann Emerg Med*. 2010;55(3):235-246.e4. doi:10.1016/j.annemergmed.2009.07.024

**43**. Myers JB, Slovis CM, Eckstein M, et al; U.S. Metropolitan Municipalities' EMS Medical Directors. Evidence-based performance measures for emergency medical services systems: a model for expanded EMS benchmarking. *Prehosp Emerg Care*. 2008;12(2):141-151. doi:10.1080/10903120801903793

**44**. Lam SS, Zhang J, Zhang ZC, et al. Dynamic ambulance reallocation for the reduction of ambulance response times using system status management. *Am J Emerg Med*. 2015;33(2):159-166. doi:10.1016/j.ajem.2014.10.044

**45**. Kononen DW, Flannagan CA, Wang SC. Identification and validation of a logistic regression model for predicting serious injuries associated with motor vehicle crashes. *Accid Anal Prev*. 2011;43(1):112-122. doi:10.1016/j.aap.2010.07.018

**46**. MacKenzie EJ, Rivara FP, Jurkovich GJ, et al. A national evaluation of the effect of trauma-center care on mortality. *N Engl J Med*. 2006;354(4):366-378. doi:10.1056/NEJMsa052049

**47**. Centers for Disease Control and Prevention. Buckle up: restraint use state fact sheets. 2015. https://www.cdc.gov/motorvehiclesafety/seatbelts/states.html. Accessed February 20, 2018.

**48**. Peura C, Kilch JA, Clark DE. Evaluating adverse rural crash outcomes using the NHTSA State Data System. *Accid Anal Prev*. 2015;82:257-262. doi:10.1016/j.aap.2015.06.005

**49**. Brown JB, Rosengart MR, Forsythe RM, et al. Not all prehospital time is equal: influence of scene time on mortality. *J Trauma Acute Care Surg*. 2016;81(1):93-100. doi:10.1097/TA.0000000000000999

**50**. Federal Interagency Committee on Emergency Medical Services. FICEM annual report to Congress. 2013. https://www.ems.gov/pdf/2011-2012-FICEMS-RTC-Mikulski.pdf. Accessed February 20, 2018.

**51**. Morgenstern H. Ecologic studies in epidemiology: concepts, principles, and methods. *Annu Rev Public Health*. 1995;16:61-81. doi:10.1146/annurev.pu.16.050195.000425