THE RELATIONSHIP BETWEEN EMERGENCY MEDICAL SERVICE RESPONSE TIME AND PREHOSPITAL DEATH FROM MOTOR VEHICLE CRASHES: RURAL-URBAN DISPARITIES AND IMPLICATIONS FOR TRAUMA SYSTEM PERFORMANCE IMPROVEMENT"

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INTRODUCTION

Motor vehicle crashes (MVCs) are the leading cause of trauma-related death in North America [1]. While MVC mortality has declined overall due to improvements in prevention, vehicle safety, and in-hospital trauma care, the proportion of deaths that occur in the prehospital environment has risen to 60% [2]. Therefore, there is need to focus on prehospital death as an endpoint for trauma system research.

Crucial to understanding this shift in MVC fatalities are the profound disparities between rural and urban regions. The annual MVC mortality rate in rural counties is three times greater than those in urban counties (30 vs. 10 per 100,000 persons) [3], equivalent to third-world nations. Emergency medical service (EMS) response times in rural regions are also characteristically prolonged and the majority of deaths occur during the prehospital time period [4].

It is possible that MVC occupants with critical injuries are more likely to succumb prior to EMS arrival in rural regions due to prolonged response times. In this scenario, patients with time-sensitive injuries would more often be classified as deaths at the scene and not transported to hospital. Conversely, efforts to shorten EMS response times would result in the transport of more high risk patients to definitive care. Since the survival of such patients is contingent on in-hospital treatment, directing resources to improve EMS response would therefore represent an actionable strategy to reduce MVC deaths in rural regions.

To inform trauma system resource allocation in North America, we evaluated the relationship between EMS response time and prehospital death among a cohort of vehicle occupants who died following MVCs on public roads in the US. We then determined the extent to which prehospital mortality is attributable to EMS response times in rural versus urban regions.

METHODS

Study Design, Participants, and Objectives: We used a retrospective cohort study design to achieve the following objectives: 1) To determine the relationship between EMS response time and risk of prehospital death, and 2) to measure the proportion of variability in prehospital mortality attributable to EMS response times across the spectrum of rurality.

Study Cohort: We identified all vehicle occupants with fatal injury due to MVCs that occurred on public roads in the US between January 1, 2001 and December 31, 2015. Crashes that involved motorcycles, heavy trucks, off-road vehicles, pedestrians, or cyclists were excluded. Counties where >10% of EMS arrival times were missing were also excluded.

Data Source: Data were derived from the Fatality Analysis Reporting System (FARS) of the National Highway Traffic Safety Administration. FARS is a population-based registry that collects information on all MVCs occurring on public roads in the US that resulted in at least one fatality within 30 days. Data captured includes variables at the occupant, vehicle, and crash level.

Exposure: The exposure was EMS response time, defined as the time elapsed between the time of the crash and the time of EMS arrival at the crash scene.

Outcome: The primary outcome was prehospital death, defined as death at the scene or en route to hospital.

Potential Confounders: We considered occupant, vehicle, and crash characteristics that might confound the relationship between EMS response time and location of death. Occupant characteristics included age, gender, seat position, restraint use, airbag deployment, ejection from the vehicle, and need for extrication. Vehicle characteristics included the body time and model year. Crash characteristics considered were multiple vehicle collision, roll over, the direction of principle impact, roadway classification, the maximum posted speed limit, pavement type and surface conditions, time of day, and year of the crash. The rurality of the crash location was classified using county population density (grouped in quartiles of <50, 50-99, 100-249, ≥250 people per square mile).

Statistical Analysis: Occupant, vehicle, and crash characteristics were compared across quartiles of EMS response time using standardized differences [5]. Standardized differences of ≥10% represented meaningful differences across quartiles [6]. Three analytic approaches were then taken.

First, survival analysis using Kaplan-Meier curves and Cox proportional hazards modelling was used to explore the relationship between EMS response time quartile and time to death.

Second, hierarchical logistic regression was used to determine the risk-adjusted relationship between EMS response time and prehospital death. This model was a mixed multilevel model [7] that included a random effects term to account for clustering of crashes with counties. EMS response time was modelled first in quartiles, and second as a continuous variable using fractional polynomials [8]. This latter approach made no underlying assumptions about the relationship being examined and helped to identify response time thresholds at which the outcome appeared to change.

Finally, the proportional of inter-county variance in prehospital death that can be explained by EMS response time was calculated using the proportional change in variance (PCV) [9]. The PCV can be calculated using the following equation:

$$PCV = [(V_1 - V_2)/V_1] \times 100$$

where V_1 is the inter-county variance in the hierarchical model that lacks the median county EMS response time, and V_2 is the variance of the same model including county response time. The PCV was calculated across deciles of county population density. This approach allowed us to determine the relative influence of EMS response times on prehospital mortality in rural versus urban crash locations.

RESULTS

We identified 83,368 vehicle occupants who were fatally-injured in 76,922 MVCs on public roads in 1,293 US counties. Occupants were predominantly male drivers with median age of 35 years. The median EMS response time was 13 minutes (IQR 8 – 21 minutes). The majority of occupants died in the prehospital environment (60%). Fewer than 1% died en route to hospital.

Higher EMS response times were associated with single vehicle crashes with roll over, crashes on county roads (vs. highways), and times between midnight and 6am. There was a strong association between rural counties and prolonged EMS response. The rate of prehospital death was significantly greater in the highest quartile of EMS response time (>21 minutes, compared to the lowest (66% vs. 52%).

Figure 1 shows the relationship between EMS response time, location and time to death. The proportion of prehospital deaths increased steadily during the first 15 minutes of EMS response time, from approximately 47% to 65% (**Figure 1A**). Concordantly, occupants in the shortest quartile of EMS response times survived significantly longer (20% vs. 15% at 6 hours), indicating that these patients were more likely to be transported to hospital where treatment efforts were undertaken (**Figure 1B**). When in-hospital deaths were examined, a greater proportion of patients in the shortest quartile of EMS response times died within the early timeframe following hospital arrival (**Figure 1C**), indicating that more critically-injured patients with high risk of early death were transported when response times were short.

Results of the hierarchical logistic regression model for prehospital death are shown in **Table 1**. Predictors of prehospital death included front seat position, ejection from the vehicle, need for extrication, vehicle roll over, higher maximum speed limit, crash between midnight and 6am, and rural crash location. Contemporary vehicle models were protective. After risk-adjustment, longer EMS response time was significantly associated with higher odds of prehospital death. When EMS response time was modelled as a continuous variable (**Figure 2A**), the odds of prehospital death increased steadily during the first 15 minutes before plateauing at approximately 1.6 beyond response times of 20 minutes.

The PCV was calculated to measure the proportion of inter-county variability in prehospital death attributable to county EMS response times. **Figure 2B** shows the results of this analysis. EMS response time explained minimal variability in prehospital death for counties with population density greater than 20 people/mile^2. However, the PCV rose sharply for counties with population densities below 20 people/mile^2, indicating that EMS response times explain a significant proportion of observed prehospital death rates in the most rural counties.

DISCUSSION

In this retrospective study of fatalities resulting from MVCs over a 15 year period, we found that EMS response time was significantly associated with greater risk of prehospital death. This effect was independent of occupant, vehicle and crash characteristics. EMS response times were significantly longer and explained a significantly greater proportion of variability in prehospital mortality in the most rural counties.

These findings have important implications for trauma system resource allocation. The disparities between rural and urban environments in North America with respect to MVC fatalities, prehospital death, and EMS response times are well documented [3]. The majority of Canada and the US are rural, with population densities <50 people/mile^2 in more than 60% of US counties. Therefore, the observation that EMS response times account for approximately 20% of the variation in prehospital mortality in counties with less than 20 people/mile^2 indicates that efforts should be directed to shorten EMS response times in these regions. In doing so, a greater proportion of critically-injured vehicle occupants will receive care in-hospital, where their outcomes might be favorably modified.

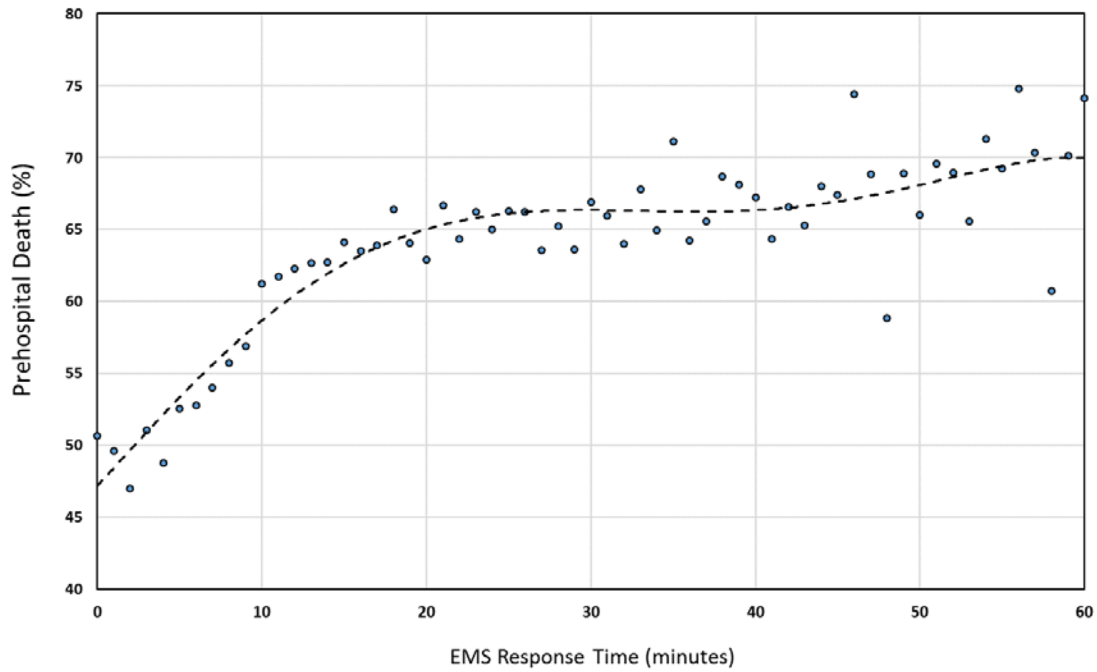
Our observations support the biological rationale for this interpretation. The finding that patients with rapid EMS response times survive significantly longer reflects that a greater proportion of critically-injured patients receive active medical care and survive to hospital when response times are short. Since non-viable patients dead at the scene are rarely transported by EMS, this may indicate that early EMS arrival is associated with greater likelihood of critically-injured patients being found with signs of life. As expected, the transport of a greater number of high risk patients resulted in a greater proportion of early deaths during the in-hospital time period. Recent studies of soldiers injured in recent military conflicts have similarly found that when prehospital times were shortened, fewer deaths occurred in the field with a concordant increase in early in-hospital deaths from wounds, resulting in a cumulative decrease in mortality [10, 11].

In summary, directing resources to achieve shortened EMS response times represents an actionable strategy for reducing prehospital deaths in the most rural counties in Canada and the US. In doing so, a greater number of critical patients with time sensitive injuries may receive treatment in-hospital, with potential for reducing overall MVC mortality.

TABLES AND FIGURES

Figure 1

A



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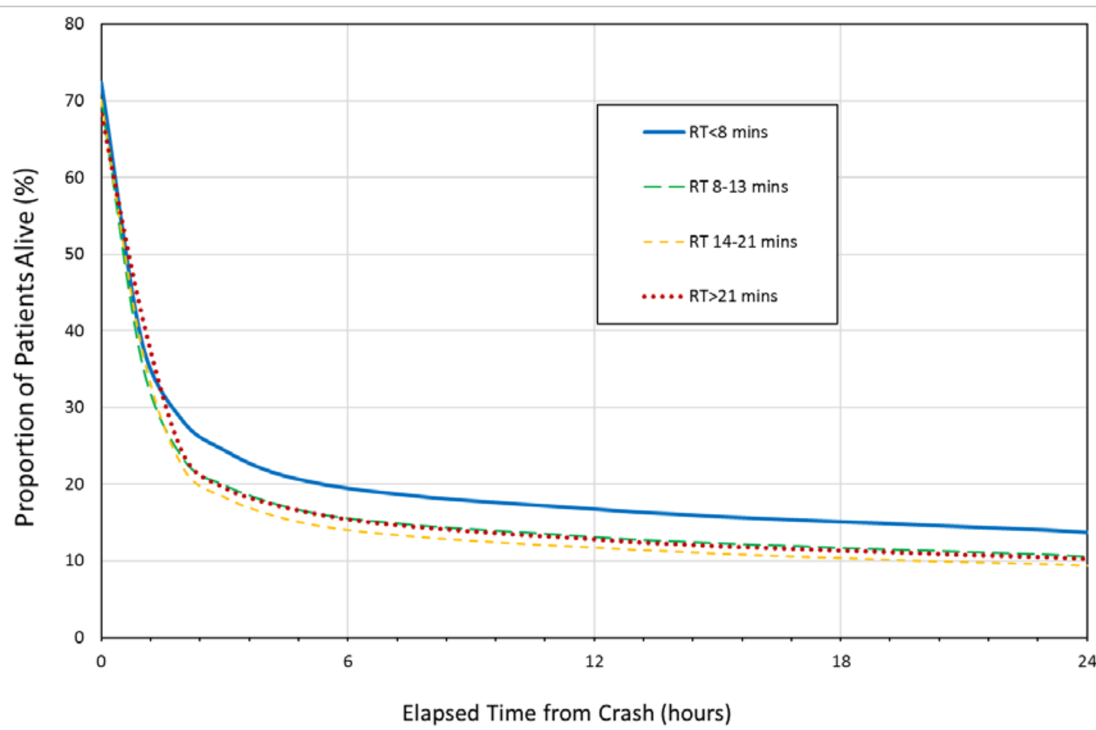

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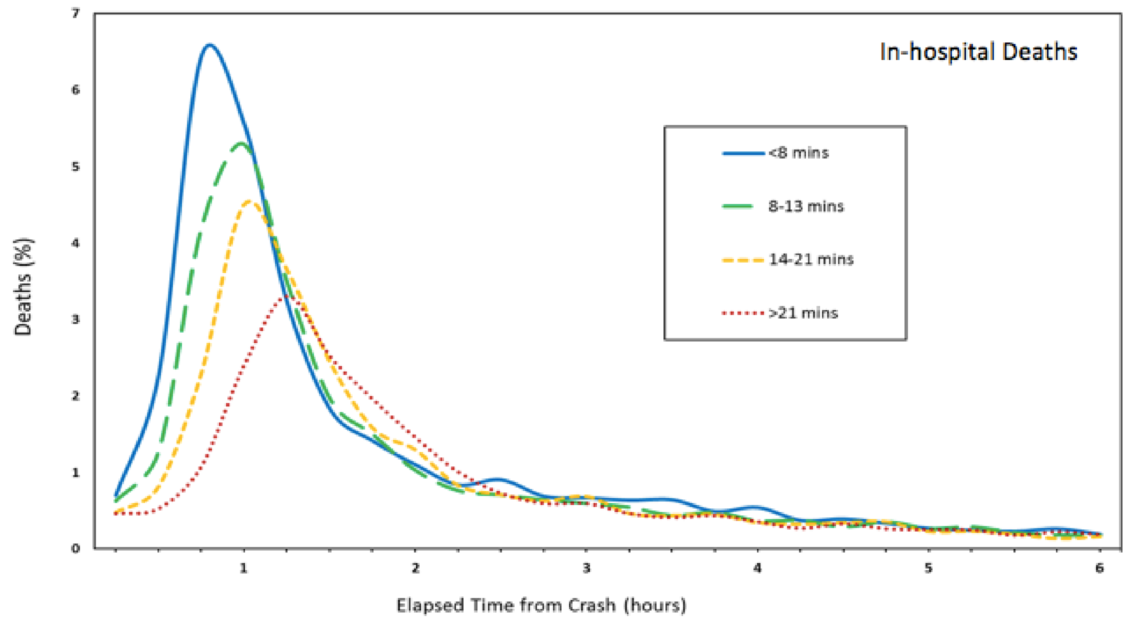


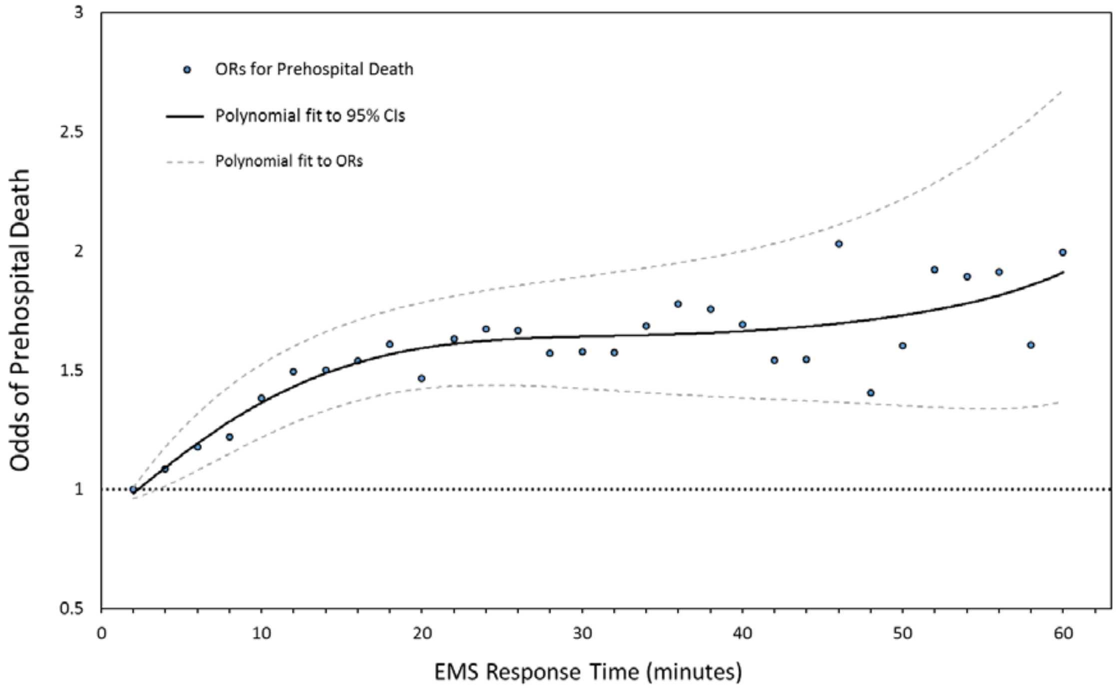
Figure 1. The relationship between EMS response time, location and time to death. **A:** Crude rate of prehospital death as a function of continuous EMS response time. **B:** Kaplan Meier curves comparing cumulative vehicle occupant survival at 24 hours between EMS response time quartiles. The shortest quartile of EMS response time (<8 minutes) was associated with significantly greater survival at 6 and 24 hours. **C:** Time to death distributions for patients treated in hospital. Shorter quartiles of EMS response time were associated with a greater proportion of early deaths, indicating the transport of more critically-injured occupants at high risk for early death.

Table 1. Multivariable model for prehospital death

Parameter	Odds Ratio	95% CI
Response time (minutes)		
< 8	Reference	NA
8 – 13	1.23	1.18 – 1.28
14 – 21	1.35	1.29 – 1.42
> 21	1.44	1.37 – 1.51
Occupant Characteristics		
Age of occupant (years)		
< 15	Reference	NA
15 – 34	1.54	1.43 – 1.67
35 – 64	1.49	1.47 – 1.72
≥ 65	0.73	0.67 – 0.80
Male gender	1.08	1.05 – 1.12
Driver	1.17	1.12 – 1.23
Front seat (vs. back)	1.16	1.08 – 1.24
Restraint use	0.96	0.93 – 0.99
Airbag deployed	1.03	1.00 – 1.07
Ejected from vehicle	1.16	1.11 – 1.21
Extrication required	1.37	1.32 – 1.43
Vehicle Characteristics		
Vehicle body type		
Sedan-sized	Reference	NA
Van or pickup	0.98	0.95 – 1.02
Year of model		
Before 1990	Reference	NA
1990 – 1999	0.96	0.91 – 1.01
2000 – 2016	0.94	0.89 – 0.99
Crash Characteristics		
Multiple vehicle crash	1.41	1.30 – 1.53
Vehicle rolled over	1.48	1.41 – 1.57
Direction of principal impact		
Front	Reference	NA
Right side	1.02	0.97 – 1.07
Left side	0.94	0.90 – 0.98
Rear	0.79	0.73 – 0.85
Other	0.89	0.84 – 0.93
Roadway classification		
Interstate or highway	Reference	NA
County road	1.08	1.03 – 1.12
Local street	0.83	0.79 – 0.88
Other	0.98	0.91 – 1.05
Speed limit (mph)		
< 35	Reference	NA
35 – 55	1.26	1.18 – 1.34
> 55	1.50	1.39 – 1.61
Unpaved road (vs. paved)	0.87	0.82 – 0.92
Time of collision		
0600 – 1159	Reference	NA
1200 – 1759	0.92	0.88 – 0.96
1800 – 2359	1.04	1.00 – 1.09
2400 – 0559	1.55	1.47 – 1.62
County population density (ppl/mile^2)		
<50	1.56	1.41 – 1.71
50 – 99	1.28	1.15 – 1.43
100 – 249	1.24	1.11 – 1.39
≥250	Reference	NA
Year of collision	1.01	1.00 – 1.02

Figure 2

A



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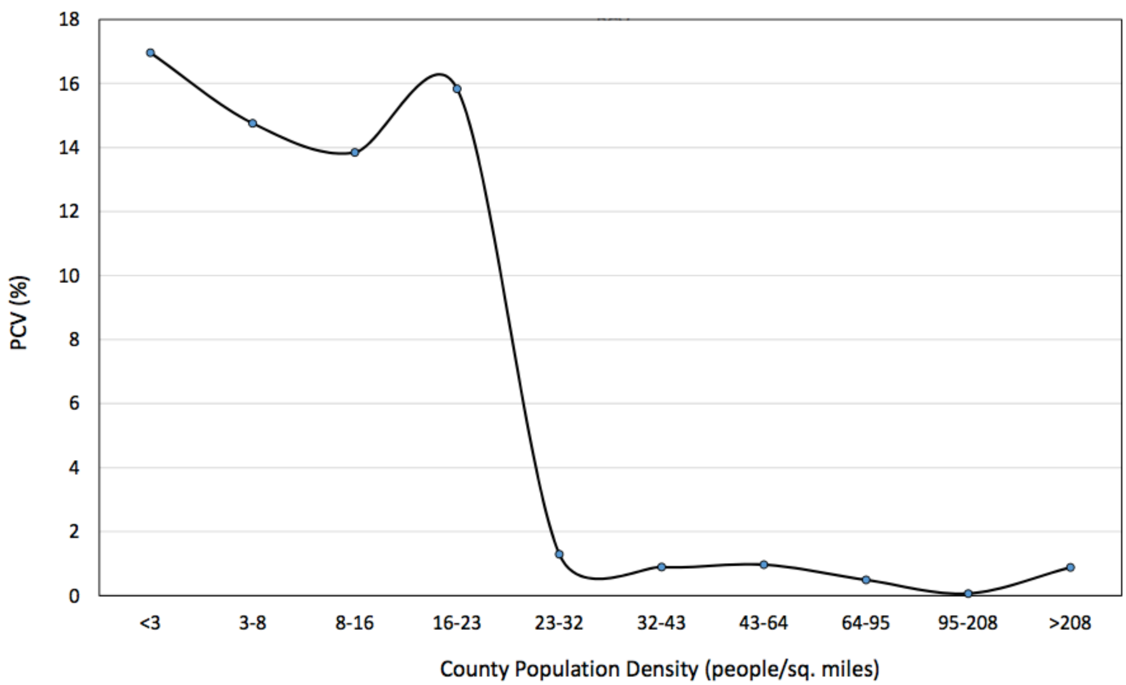

Figure 2. A: Results of the hierarchical logistic regression model for prehospital death with EMS response time modelled as a continuous variable. The odds of prehospital death increased most during the first 15 minutes, before plateauing beyond response times of 20 minutes. **B:** Proportional change in variance analysis. Points represent the proportion of variability in prehospital death at the county level explained by EMS response times. EMS response times explained a large proportion of prehospital death rates for the most rural counties with population density below 20 people/mile^2.

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