THE JOURNAL OF PEDIATRICS • www.jpeds.com

Factors Associated with Pediatric Mortality from Motor Vehicle Crashes in the United States: A State-Based Analysis

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Objective To examine geographic variation in motor vehicle crash (MVC)-related pediatric mortality and identify state-level predictors of mortality.

Study design Using the 2010-2014 Fatality Analysis Reporting System, we identified passengers <15 years of age involved in fatal MVCs, defined as crashes on US public roads with ≥1 death (adult or pediatric) within 30 days. We assessed passenger, driver, vehicle, crash, and state policy characteristics as factors potentially associated with MVC-related pediatric mortality. Our outcomes were age-adjusted, MVC-related mortality rate per 100 000 children and percentage of children who died of those in fatal MVCs. Unit of analysis was US state. We used multivariable linear regression to define state characteristics associated with higher levels of each outcome.

Results Of 18 116 children in fatal MVCs, 15.9% died. The age-adjusted, MVC-related mortality rate per 100 000 children varied from 0.25 in Massachusetts to 3.23 in Mississippi (mean national rate of 0.94). Predictors of greater age-adjusted, MVC-related mortality rate per 100 000 children included greater percentage of children who were unrestrained or inappropriately restrained ($P < .001$) and greater percentage of crashes on rural roads ($P = .016$). Additionally, greater percentages of children died in states without red light camera legislation ($P < .001$). For 10% absolute improvement in appropriate child restraint use nationally, our risk-adjusted model predicted >1100 pediatric deaths averted over 5 years.

Conclusions MVC-related pediatric mortality varied by state and was associated with restraint nonuse or misuse, rural roads, vehicle type, and red light camera policy. Revising state regulations and improving enforcement around these factors may prevent substantial pediatric mortality. *(J Pediatr 2017;■■:■■-■■).*

Unintentional injury is the leading cause of pediatric death in the US, and motor vehicle crashes (MVCs) are the most common cause of injury.[1] Over the past 20 years, many studies have analyzed individual, person-level data and identified several risk factors for MVC-related mortality in children, including nonuse of restraints,[2-5] front seat position,[4-6] alcohol-impaired drivers,[7-10] younger driver age,[9] high speed roads,[9,11] and rural roads.[12,13] In 2011, informed by this research, the American Academy of Pediatrics published specific guidelines regarding the strongest and most modifiable predictors—namely, child restraints and seat position.[14] Prior guidelines have also addressed alcohol use by drivers.[15] Although these recommendations have been implemented in part by some states, no state has implemented them fully.[16]

Further, no prior study has examined trends in MVC-related pediatric mortality across states and factors associated with geographic variation at the state or regional level. This geographic variation is important because laws regarding child traffic safety remain within the state domain.[17] It is vital, therefore, to understand how state-level regulations and their implementation and enforcement impact MVC-related pediatric mortality. We hypothesized that state-level policies related to child traffic safety would be associated with state mortality rates. Our objectives were to assess for variation in MVC-related pediatric mortality by state and region and to explain the sources of such variation.

Methods

We performed a retrospective analysis of data to inform state-level policy. We compiled our analytic dataset from multiple sources. The primary source was the

AAMR	Age-adjusted, mean MVC-related pediatric mortality per 100 000 children
FARS	Fatality Analysis Reporting System
MVC	Motor vehicle crash

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Supported by the American College of Surgeons Resident Research Scholarship (to L.W.) and the US National Institute of Health/National Institute of Arthritis and Musculoskeletal and Skin Diseases (K24AR057827-02 [to E.L.]). A.H. is the PI of a contract (AD-1306-03980) with the Patient-Centered Outcomes Research Institute entitled "Patient-Centered Approaches to Collect Sexual Orientation/Gender Identity in the ED" and a Harvard Surgery Affinity Research Collaborative (ARC) Program Grant entitled "Mitigating Disparities Through Enhancing Surgeons' Ability To Provide Culturally Relevant Care." The other authors declare no conflicts of interest.

Portions of this study were presented as an oral presentation at the American Academy of Pediatrics National Conference & Exhibition in San Francisco, California, October 21-25, 2016.

http://dx.doi.org10.1016/j.jpeds.2017.04.044

Fatality Analysis Reporting System (FARS), a nationwide census providing publicly available data on fatalities associated with MVCs. The FARS includes all fatal crashes in the US, defined as crashes that occur on a public road and result in ≥1 death (adult or pediatric) within 30 days. Data collection is supervised by the National Highway Traffic Safety Administration and data are compiled from various documents in each state, including police accident reports, death certificates, state vehicle registration files, medical examiner reports, state driver licensing files, state highway department data, emergency medical service reports, and vital statistics. Data are subjected to checks for acceptable range values and consistency, as well as quality checks.[18] We obtained annual US population size estimates by age, state, and region, and the percentage of households with a vehicle from the US Census.[19,20] We compiled state-level policies relevant to child traffic safety from the Governors Highway Safety Association, the Insurance Institute for Highway Safety (a US nonprofit research organization funded by auto insurers), and the medical and legal literature.[17,21,22] We assembled data from 2010 to 2014 to coincide with the most recently available FARS data.

We defined a study cohort using person-level data from children <15 years of age riding in a passenger vehicle involved in a fatal crash (**Figure 1**; available at www.jpeds.com). Passenger vehicles are defined by the National Highway Traffic Safety Administration as cars, sport utility vehicles, vans, and pickup trucks with a gross weight of ≤10,000 pounds.[18,23] We excluded children classified as drivers, passengers on a motorcycle/bicycle, or pedestrians, as well as children in an unenclosed passenger or cargo area, the vehicle exterior, or a trailing unit. We made these exclusions to focus on state-level policies, such as guidelines for restraint use, that would apply to all children in our study population. We used a complete case analysis approach for the individual observations, excluding observations with missing data for key variables from all analyses. Data were missing for <5% of observations for all variables except for restraint use/misuse, which was missing for 6% of observations.

Our primary outcome was state-based, age-adjusted, mean MVC-related pediatric mortality per 100 000 children (AAMR) between 2010-2014, defined as 30-day mortality from the day of the crash. We calculated age-adjusted mortality rates per 100 000 children for each state using census information on the pediatric population for 5 age groups (0-2, 3-5, 6-8, 9-12, or 13-14 years of age) within each state, standardized by the population within these age groups in the US overall. Age groups were selected based on recommended seating within a motor vehicle at different ages. We then obtained mean mortality rates by averaging the annual rates over the 5-year period of 2010-2014. Owing to state-level differences in vehicle ownership and the amount of time children may spend as passengers in a vehicle, we considered a secondary outcome, the percentage of children who died of those involved in a fatal crash.[20] We calculated both outcomes by region (Midwest, Northeast, South, West) and nationally.

To explain state-level variation in mortality rates, we compiled an extensive list of variables potentially related to MVC-related pediatric mortality, including passenger, driver, vehicle, crash, and state policy characteristics (**Appendix**; available at www.jpeds.com). Most person-, vehicle-, and crash-level variables were used as defined in the FARS. Of note, the FARS dataset reported type of restraint and any indication of misuse of the restraint system. Additionally, we defined several variables. Child passengers riding in the front seat were deemed appropriate or inappropriate based on the American Academy of Pediatrics guidelines that children <13 years of age should ride in the rear seats of vehicles.[14] Vehicle type was categorized as car, sport utility vehicle, van/minivan, pickup truck, or vehicle larger than a pickup truck. Crashes occurring over the weekend were defined as those between Friday 5 p.m. and Monday 6 a.m. Crashes occurring during the day were defined as those between 6 a.m. and 6 p.m.[24] We modeled state speed and red light camera policy using dummy variables (state legislation present vs not present, prohibited vs not prohibited, limited vs not limited, permitted vs not permitted) as well as by current use patterns (in use vs not in use). We categorized the variables into 4 main topical groups: (1) restraints or seat position,[2,3,6,9,23,25] (2) speeding or traffic restrictions,[8,9,11,23] (3) driving under the influence of alcohol,[7-10] and (4) availability of pediatric trauma centers and trauma systems.[26-31]

Statistical Analyses

We performed an ecological study using US state as our unit of analysis. We summarized person-level data for all children meeting the inclusion and exclusion criteria to obtain mean state-level values for each variable. We used multivariable linear regression to identify state characteristics associated with greater AAMR or percentage of children who die when involved in a fatal crash. For each outcome, we used stepwise model building; this approach allowed us to obtain the most parsimonious model that represented the geographic variation of MVC-related pediatric mortality without concern for overfitting the data. We included all identified variables of interest in the initial model-building process for each outcome.

We first assessed Pearson correlation coefficients between each outcome and each potential continuous predictor. We identified continuous variables that met 2 criteria: (1) correlation with the outcome, expressed by Pearson correlation of >0.3 or <–0.3 and (2) $P \leq .10$. Variables that met these criteria were included in a correlation matrix; we removed highly collinear variables (bivariate Pearson correlation ≥ 0.6), keeping the variable with the highest Pearson correlation with the outcome in the model in each instance of collinearity. For categorical and binary variables, we used ANOVA and *t*-tests, respectively, to identify variables with an association with the outcome with a *P*-value of ≤.10. We included all selected variables in an initial model, using a process of stepwise selection to remove nonsignificant variables ($P > .10$) until we obtained a final model for each outcome. In all models for the primary outcome, the percentage of households with a vehicle was included regardless of significance owing to its likelihood to be a confounder.

Analyses were performed using SAS 9.4 (SAS Institute, Cary, North Carolina). A 2-sided *P*-value of .05 was used to determine

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significance in the final models. The Partners Human Research Committee approved this research.

Results

After applying the inclusion and exclusion criteria, we established a cohort of 18 116 children (**Figure 1**). This national cohort had a mean age of 6.9 years (SD 4.4) and was 51% male. The majority of children involved in a fatal crash lived in the South (52%), with 21% in the West, 19% in the Midwest, and 7.5% in the Northeast. Of the 18 116 children involved in a fatal crash, 2885 died (15.9%) within 30 days, of which 1424 died at the scene of the MVC. This corresponded with an overall AAMR for the US of 0.94 per 100 000 children.

Crash characteristics by state are shown in **Table I**. On average across all states, 20% of children involved in a fatal crash were unrestrained or inappropriately restrained at the time of the crash, 13% were inappropriately seated in the front seat, and nearly 9% of drivers carrying a child passenger were under the influence of alcohol. Crashes were most likely to occur on state highways (35%) and on roads classified as rural by the Federal Highway Authority (62%).[18] Vehicles involved in fatal crashes had been on the road for an average of 9.4 years (SD 1.1). Consistent with the nature of the FARS, the vast majority of vehicles sustained disabling damage. Policy characteristics within the 4 identified domains varied considerably by state (**Table I**).

There was substantial state-level variation of the key predictors selected through our model-building process (**Table II**). The percentage of children involved in a fatal crash who were unrestrained or inappropriately restrained varied from 2% in New Hampshire to 38% in Mississippi. Characteristics of the crashes also varied: the percentage of those that occurred on a rural road varied from 17% in Massachusetts and Rhode Island to 100% in Maine and Vermont; the percentage of those that occurred on state highways varied from 11% in Iowa to 84% in Hawaii; and the percentage of those that occurred on a road with a speed limit of 65-80 mph varied from 0% in Hawaii, Maine, and Rhode Island to 80% in Wyoming (**Table II**).

The number of fatal crashes between 2010-2014 ranged from 18 in Rhode Island to 2017 in Texas, and the number of deaths ranged from 3 in Rhode Island to 346 in Texas. The AAMR per 100 000 children varied from 0.25 in Massachusetts to 3.23 in Mississippi. The percentage of children who died of those involved in a fatal crash varied from 8% in New Hampshire to 30% in Nebraska (**Table III**; available at www.jpeds.com). The geographic distribution of AAMR and percentage of children who died of those involved in a fatal crash are illustrated graphically in **Figure 2**.

Predictors of State-Level Mortality

Primary Outcome. Based on our stepwise model-building process, we identified several state-level predictors associated with each outcome. In the model for AAMR, the factors that were significantly independently associated with increased mortality rates were a child being unrestrained or inappropriately

Table I. Summary of states' crash characteristics for fatal crashes involving a child passenger, 2010-2014 and state policy characteristics relevant to child motor vehicle safety

Factors	
State crash characteristics, mean (SD)	
Driver age (y)	36 (1.9)
Driver under the influence of alcohol (%)	8.9 (4.4)
Child inappropriately seated in front seat (%)	13 (3.2)
Child unrestrained or inappropriately restrained (%)	20 (8.4)
Road location (%)	
Interstate	16 (8.3)
US highway	20 (11)
State highway	35 (16)
County road	12 (11)
Local street	15 (11)
Rural road (%)*	62 (21)
Vehicle type (%)	
Car	42 (8.9)
Van/minivan	14 (6.8)
Sport utility vehicle	24 (6.0)
Pickup truck	17 (7.2)
Vehicle years on the road (y)	9.4 (1.1)
Speed limit at crash site (mph) (%)	
5-20	0.5 (1.0)
25-40	22 (12)
45-60	52 (17)
65-80	24 (18)
None	0.8 (2.5)
Crash during the day (6 a.m.-6 p.m.) (%)	64 (7.2)
Crash over the weekend† (%)	46 (5.9)
Disabling damage to vehicle (%)	84 (11)
Rollover mechanism (%)	24 (11)
Child ejected from vehicle (%)	8.0 (5.0)
Child extricated from vehicle (%)	9.0 (6.6)
State policy characteristics	
Restraints or seat position	
Law states a preference for seating children in the rear seat, % of states	34
Allows primary enforcement of seat belt laws for children, % of states	68
Requires a rear-facing seat for children <1y or <20 pounds, % of states	30
Maximum fine for first offense violating state child restraint laws ($), mean (SD)	67 (70)
Maximum fine for first offense violating state seat belt laws ($), mean (SD)	34 (33)
Speeding or traffic restrictions	
Legislation in place regarding speed camera use, % of states	50
Legislation in place regarding red light camera use, % of states	34
Maximum state speed limit (mph), mean (SD)	71 (5.5)
Driving under the influence of alcohol	
Administrative license suspension on first offense/refusal to submit to a chemical test, % of states	90
Open container law meeting federal requirements,‡ % of states	80
Repeat offender law meeting federal requirements,‡ % of states	72
Mandatory vehicle or license plate sanctions, % of states	60
Availability of pediatric trauma centers/trauma systems	
Funded state trauma system, % of states	58
State has ≥1 level 1 or level 2 pediatric trauma center, % of states	64
Total level 1 and level 2 pediatric trauma centers per 100 000 children, mean (SD)	0.18 (0.20)

*The distinction between rural and urban roads was as defined by the Federal Highway Administration.[18]
†Weekend was defined as Friday 5 p.m. to Monday 6 a.m.
‡Federal law specifies minimum requirements for state open container and repeat offender laws. If these are not met, National Highway System, Surface Transportation Program, and Interstate Maintenance funds are instead transferred into each state's State and Community Highway Safety Grant Program (Section 402).[32,33]

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Table II. State variation of key predictors for fatal crashes involving a child passenger, 2010-2014

States	No restraint use/misuse (%)	On rural road (%)	Vehicle type van (%)	On state highway (%)	Speed limit 65-80 mph (%)	Red light camera policy
Midwest	21	71	20	27	25	—
Illinois	22	45	21	29	11	Limited
Indiana	19	72	27	29	15	No law
Iowa	24	71	33	11	20	No law
Kansas	25	77	15	14	43	No law
Michigan	9	54	21	24	12	No law
Minnesota	21	74	19	28	17	No law
Missouri	20	62	13	49	19	Limited
Nebraska	34	86	15	15	41	No law
North Dakota	25	93	22	24	47	No law
Ohio	14	62	17	34	9	Limited
South Dakota	30	87	13	28	61	No law
Wisconsin	10	68	25	41	10	Prohibited
Northeast	11	50	18	44	11	—
Connecticut	10	20	11	39	15	No law
Maine	5	100	31	50	0	Prohibited
Massachusetts	13	17	25	36	23	No law
New Hampshire	2	50	15	53	10	Prohibited
New Jersey	13	18	20	26	14	Prohibited
New York	11	72	21	33	14	Limited
Pennsylvania	15	59	20	58	7	Limited
Rhode Island	17	17	6	56	0	Permitted
Vermont	18	100	11	46	14	No law
South	23	63	11	37	20	—
Alabama	33	64	9	26	23	Limited
Arkansas	17	83	9	43	20	Prohibited
Delaware	33	58	6	67	6	Permitted
Florida	16	39	15	30	20	Permitted
Georgia	23	48	13	38	17	Permitted
Kentucky	16	77	12	57	12	No law
Louisiana	32	51	8	51	13	Limited
Maryland	15	40	20	49	8	Permitted
Mississippi	38	81	5	29	32	Prohibited
North Carolina	15	71	14	30	12	Limited
Oklahoma	23	66	8	30	46	No law
South Carolina	19	79	13	40	18	Prohibited
Tennessee	21	53	12	32	13	Permitted
Texas	21	55	7	20	41	Limited
Virginia	26	66	17	22	14	Limited
West Virginia	21	67	11	30	24	Prohibited
West	22	63	10	32	37	—
Alaska	14	62	0	76	19	No law
Arizona	24	41	14	13	42	Permitted
California	13	46	14	27	32	Permitted
Colorado	26	50	11	22	36	Permitted
Hawaii	20	50	4	84	0	No law
Idaho	23	75	14	20	43	No law
Montana	30	92	8	21	73	Prohibited
Nevada	23	45	14	25	41	Prohibited
New Mexico	32	76	14	18	46	Limited
Oregon	13	77	12	27	9	Permitted
Utah	23	51	8	36	38	No law
Washington	5	59	14	33	17	Limited
Wyoming	37	89	9	16	80	No law
US Overall	20	62	14	35	24	—

restrained and the crash occurring on a rural road. For each 1% increase in the percentage of children who were unrestrained or inappropriately restrained, the AAMR increased by 0.038 (95% CI 0.020-0.057). Similarly, for each 1% increase in the percentage of crashes occurring on rural roads, the AAMR increased by 0.009 (95% CI 0.002-0.017). A protective effect was associated with the percentage of children riding in a vehicle classified as a van/minivan. For each 1% increase in the percentage of children riding in vans, the AAMR decreased by 0.021 (95% CI 0.001-0.042). These factors explained 68% of the variability in AAMR by state (Table IV).

Secondary Outcome. In the model for percentage of children who died of those involved in a fatal crash, factors that were significantly independently associated with increased likelihood of death were, again, a child being unrestrained or inappropriately restrained and the crash occurring on a rural road, as well as absence of state legislation regarding red light cameras.

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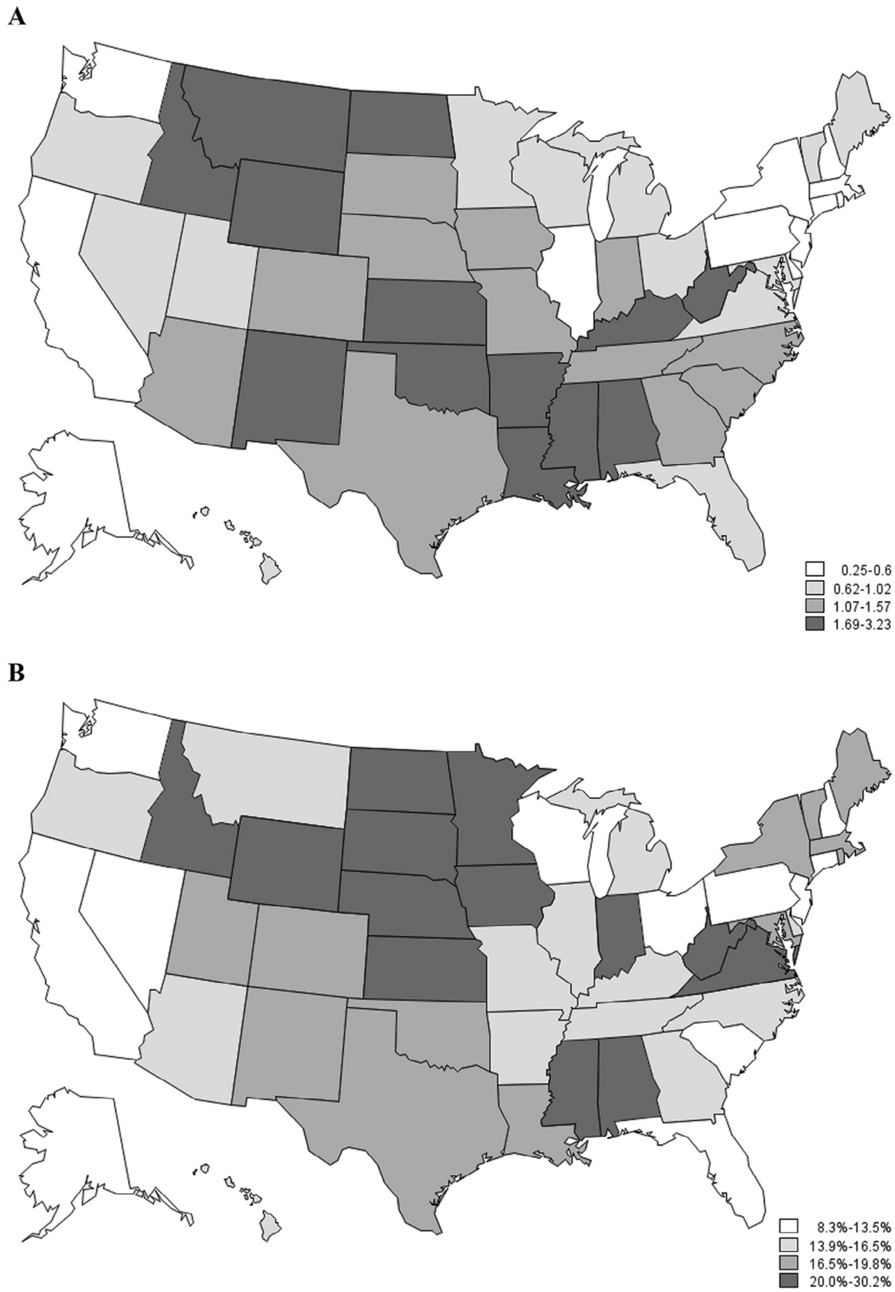

Figure 2. Age-adjusted mean mortality rates from MVCs per 100 000 children, ages 0-14, 2010-2014 (**A**) and percentage of children who died in a severe MVCs, ages 0-14, 2010-2014 (**B**).

For each 1% increase in the percentage of children who were unrestrained or inappropriately restrained, the percentage of children who died increased by 0.33% (95% CI 0.21-0.44). Similarly, for each 1% increase in the percentage of crashes occurring on rural roads, the percentage of children who died increased by 0.05% (95% CI 0.01-0.09). In states without legislation in place regarding red light cameras, the percentage of children who died was on average 3.73% higher (95% CI 1.97-5.48), compared with states with legislation in place. Protective effects were associated with the percentage of crashes occurring on state highways and percentage of crashes occurring on roads with a speed limit of 65-80 mph. For each 1% increase in the percentage of crashes occurring on state highways, the percentage of children who died decreased by 0.13% (95% CI 0.07-0.20). Similarly, for each 1% increase in the percentage of crashes occurring on roads with a speed limit of 65-80 mph, the percentage of children who died decreased by 0.11% (95% CI 0.05-0.18). Together, these factors explained 67% of the variability in percentage of children who died of those involved in a fatal crash (Table IV).

The state-level variability suggests the potential for state and regional improvements in mortality. Further, if the identified

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Table IV. State-level predictors of mortality: multivariable linear regression models for age-adjusted mortality rate per 100 000 children and percentage died of those involved in a fatal crash

Factors	Change in mortality rate per 100 000 children for each absolute % change in predictor	*P* value
Age-adjusted mortality rates per 100 000 children		
Percentage of children unrestrained or inappropriately restrained	0.038	<.001
Percentage of crashes on a rural road	0.009	.016
Percentage of children in vans	–0.021	.057
Percentage of crashes on a US highway	0.015	.076
Percentage of households with a vehicle	0.014	.466
Model R^2	0.68	
	Change in percentage died for each absolute % change in predictor	
Percentage died of those involved in a fatal crash		
Percentage of children unrestrained or inappropriately restrained	0.33	<.001
Percentage of crashes on a state highway	–0.13	<.001
Percentage of crashes occurring in 65-80 mph zones	–0.11	.002
Percentage of crashes on a rural road	0.05	.012
	Change in percentage died	
No state legislation on red light cameras (vs state legislation)	3.73	<.001
Model R^2	0.67	

risk factors are addressed, the models predict sizable improvements in MVC-related pediatric mortality nationally. For instance, a potential 10% absolute improvement in child restraint use—decreasing the average number of unrestrained or inappropriately restrained children from 20% to 10% nationally—would decrease the national age-adjusted MVC-related mortality rate from 0.94 to 0.56 per 100 000 children. For the current national population of 61.0 million children, this would lead to approximately 232 pediatric deaths averted per year. Over 5 years, this translates to >1100 pediatric deaths averted, or nearly 40% of the deaths observed over the 2010-2014 period.

Discussion

We analyzed data from the National Highway Traffic Safety Administration's FARS to assess geographic variation of pediatric mortality from MVCs in the US and found substantial variation by state in AAMR as well as percentage of children who die of those involved in a fatal crash. Percentage of nonuse or misuse of restraints was a key predictor for both outcomes. Additional state-level characteristics that predicted increased risk of death included a greater percentage of crashes on rural roads and absence of state red light camera legislation. Protective effects were observed for percentage of children riding in vans, percentage of crashes occurring on a state highway, and percentage of crashes occurring on roads with a speed limit of 65-80 mph. We quantified the potential impact of improving appropriate child restraint use, with a prediction of ≥1100 deaths averted over the next 5 years if the prevalence of unrestrained or inappropriately restrained children were reduced from 20% to 10% nationally.

These data are consistent with and extend those from prior reports. The cohort had similar age and sex characteristics compared with prior studies of child passengers involved in MVCs.[34,35] Multiple studies have shown increased risk of death for children who are unrestrained or inappropriately restrained.[2-4,9] A prior analysis of 2000-2005 FARS data in conjunction with a national sample of police-reported crashes, the National Automotive Sampling System, estimated risk-adjusted odds of death ranging from 6 to 17 times higher for unrestrained child passengers 8-17 years of age in a tow-away crash, compared with those who were restrained.[9] In younger children, another FARS/National Automotive Sampling System study found a 28% reduction in risk of death when children 2-6 years of age were restrained with an appropriate child seat, compared with a seat belt.[3] In addition, a national survey found that inappropriately restrained children <16 years of age were nearly twice as likely to sustain a clinically significant injury and unrestrained children were >3 times as likely, compared with appropriately restrained children.[36] Our findings highlight the importance of appropriate child restraint use; further, we present the results on the state level, where they may be best used by policymakers.

Rural roads have been previously associated with increased risk of death in a population-based study in Canada, which found the relative risk of MVC fatality to be 5 times higher in rural areas, compared with urban areas.[13] In addition, rural roads may be associated with other factors not measured in our data, including poorer road quality, decreased lighting/visibility, decreased enforcement of speed limits, objects on the roadside, or distance to the nearest trauma center. Driver familiarity with rural roads may contribute to risk; a study of rural and urban drivers in Utah found that drivers residing in an urban county were nearly 3 times as likely to die in a crash in a rural area, compared with drivers residing in a rural county.[12]

Of 20 different policy-specific variables examined in the analysis, the only one that remained significant in a final model

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was state-level policy on red light cameras. We found a higher risk of death in states without legislation regarding red light cameras. Prior evaluations of red light cameras have mixed results. A 2005 Cochrane review including 10 controlled before–after studies found that red light cameras are effective in reducing total fatal crashes, with results less conclusive on total collisions and violations.[37] More recently, another review published similar findings.[38] However, there has been methodological critique of the published studies, with some authors arguing that red light cameras may not improve and may actually increase crashes and injuries.[39,40] To date, there are no randomized, controlled trials published on red light cameras. Our findings suggest an association between states that have legislation either permitting or prohibiting red light cameras and lower state MVC-related pediatric mortality; having legislation in place regarding red light cameras may be a proxy for a state's overall interest in prioritizing legislation and enforcement of traffic safety measures. Notably, other policy-specific variables, including those addressing seat belt and car seat laws, did not have significant associations with the outcomes. This finding suggests that there may be a gap between legislation and enforcement of these regulations.

We observed protective effects for several variables. Increased percentage of crashes in which the child was riding in a van was associated with decreased mortality, consistent with known better occupant protection in light trucks and vans vs cars.[41] However, current evidence suggests that the protective benefit of larger vehicles must be balanced with increased threat of injury to pedestrians and occupants of smaller vehicles.[41-43] Protective associations from state highways and roads with speed limits of 65-80 mph are more challenging to understand. Although several studies demonstrated increased MVC-related mortality associated with increased speed limits after the 1995 repeal of the national maximum speed limit,[44-47] 1 state-level study in Utah did not identify a "major overall effect of [national maximum speed limit] repeal and increased speed limit on crash occurrence on Utah highways."[48] Our estimates represent the independent effect of each factor. For instance, the bivariate correlation between roads with speed limits of 65-80 mph and the percentage of children who died of those involved in a fatal MVC was positive. However, after adjusting for the other factors in the model—including restraint use—the independent effect of speed limit became protective. This may reflect unmeasured characteristics of roads with high speed limits, such as better maintenance, fewer curves, wider lanes and shoulders, and more expeditious access by emergency medical vehicles.[49]

The implications of this work are twofold. First, the nature of the factors identified as predictive of pediatric mortality from fatal crashes suggests that state policy characteristics are an important mechanism to decrease pediatric deaths from MVCs. Further, full implementation of policies is necessary to ensure child safety—uneven implementation and enforcement may contribute to the state-level variation we observed. Previous research has discussed the potential for a federal intervention in the area of child traffic safety if states are not able to implement policies successfully.[17] Absent this, there remains need for close collaboration between the injury prevention community and those enacting and enforcing legislation.[50]

The results of this study must be interpreted in the context of the study design. The strength of the FARS dataset is that it includes all MVC occurrences, allowing us to understand the national distribution of MVCs. However, FARS only provides information on crashes with ≥1 fatality, and the National Automotive Sampling System, a national sample of all MVCs, does not provide state-level information. These policies limited our ability to understand pediatric deaths from MVCs in the context of all MVCs. We addressed this by using 2 different outcomes: AAMR (which was not dependent on the total number of crashes) and percentage of children who died of those involved in a fatal crash. Although the ecological study design was well-suited to broadly define key policy areas that may improve MVC-related pediatric mortality, we were not able to examine intricacies surrounding some of the variables; for instance, red light cameras are thought to reduce angle crashes only, which was not represented in our analysis.

In conclusion, we found substantial geographic variation in likelihood of death for children involved in a fatal MVC. The percentage of children who are unrestrained or inappropriately restrained is a leading predictor of mortality; this supports recommendations from the American Academy of Pediatrics that uniform enforcement of appropriate child safety restraints is crucial to reduce MVC-related child deaths. In addition, we found that state law surrounding red light cameras may be an influential policy area related to MVC-related pediatric mortality. Further research is required to understand how vehicle type, roadway characteristics, speed limits, and red light camera use may contribute to overall risk of death. However, the results on child restraints are clear: policy and enforcement interventions have the potential for substantial impact on the reduction of MVC-related pediatric mortality. ■

Submitted for publication Dec 17, 2016; last revision received Mar 3, 2017; accepted Apr 20, 2017

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Appendix

Variables Included in Model-Building Process

Variable	Range
Passenger level	
Mean age (y) of child passenger	5.4-8.2
Percentage of child passengers that were female	36-64
Percentage of children ejected from the vehicle	0-22
Percentage of children extricated from the vehicle	0-25
Percentage of children seated in the front seat	9-29
Percentage of children seated inappropriately in the front seat	5-19
Percentage of children unrestrained or inappropriately restrained	2-38
Driver level	
Mean driver age (y)	29.6-39.7
Percentage of crashes with driver age < 20 y	0-28
Percentage of crashes with driver age 20-24 y	0-19
Percentage of crashes with driver age > 24 y	66-97
Percentage of crashes with driver under the influence of alcohol	1-28
Vehicle level	
Mean vehicle years on the road	6.6-11.8
Percentage of all vehicles in a crash that were cars	19-63
Percentage of all vehicles in a crash that were vans/minivans	0-33
Percentage of all vehicles in a crash that were sport utility vehicles	11-49
Percentage of all vehicles in a crash that were pickup trucks	6-36
Percentage of all vehicles in a crash that were larger than a pickup truck	0-11
Percentage of all vehicles in a crash with disabling damage	41-100
Percentage of all vehicles in a crash with intrusion	0-6
Percentage of all vehicles in a crash with rollover mechanism	5-64
Crash level	
Mean speed limit (mph) at crash site	39-66
Percentage of crashes occurring in a 5-20 mph speed limit zone	0-5
Percentage of crashes occurring in a 25-40 mph speed limit zone	4-55
Percentage of crashes occurring in a 45-60 mph speed limit zone	11-81
Percentage of crashes occurring in a 65-80 mph speed limit zone	0-80
Percentage of crashes occurring in a zone with no speed limit	0-18
Percentage of crashes occurring on an interstate	0-47
Percentage of crashes occurring on a US highway	0-51
Percentage of crashes occurring on a state highway	11-84
Percentage of crashes occurring on a county road	0-42
Percentage of crashes occurring on a local street	0-44
Percentage of crashes occurring on other roadway	0-32
Percentage of crashes occurring on a rural road	17-100
Percentage of crashes occurring during the day (6 a.m.-6 p.m.)	50-79
Percentage of crashes occurring over the weekend (Fri 5 p.m.-Mon 6 a.m.)	32-64
Percentage of crashes occurring in the winter (Dec-Feb)	6-68
Percentage of crashes occurring in the spring (Mar-May)	4-39
Percentage of crashes occurring in the summer (Jun-Aug)	11-66
Percentage of crashes occurring in the fall (Sep-Nov)	7-44
State policy level	
State open container law meeting federal requirements	0-1
State repeat offender law (for driving under the influence) meeting federal requirements	0-1
State administrative license suspension on first offense/refusal to submit to a chemical test for driving under the influence	0-1
State mandatory vehicle or license plate sanctions for driving under the influence	0-1
State maximum fine for first offense violating state child restraint laws	10-500
State maximum fine for first offense violating state seat belt laws	0-200
State maximum allowed speed limit	55-85
State law stating a preference for seating children in the rear seat	0-1
State has ≥1 level 1 pediatric trauma center	0-1
State number of level 1 pediatric trauma centers	0-5
State has ≥1 level 1 or 2 pediatric trauma center	0-1
State number of level 2 pediatric trauma centers	0-4
State number of level 1 and level 2 pediatric trauma centers	0-8
State number of level 1 and level 2 pediatric trauma centers per 100 000 children	0-0.75
State trauma system in place (none, unfunded, funded)	0-2
State requires children to be in a rear-facing child safety seat when <1 y or <20 pounds	0-1
State red light camera legislation present	0-1
State red light camera use prohibited	0-1
State red light camera use limited	0-1
State red light camera use permitted	0-1
State red light cameras in current use	0-1
State speed camera legislation present	0-1
State speed camera use prohibited	0-1
State speed camera use limited	0-1
State speed camera use permitted	0-1
State speed cameras in current use	0-1
State law allowing primary enforcement of seat belt laws for children	0-1

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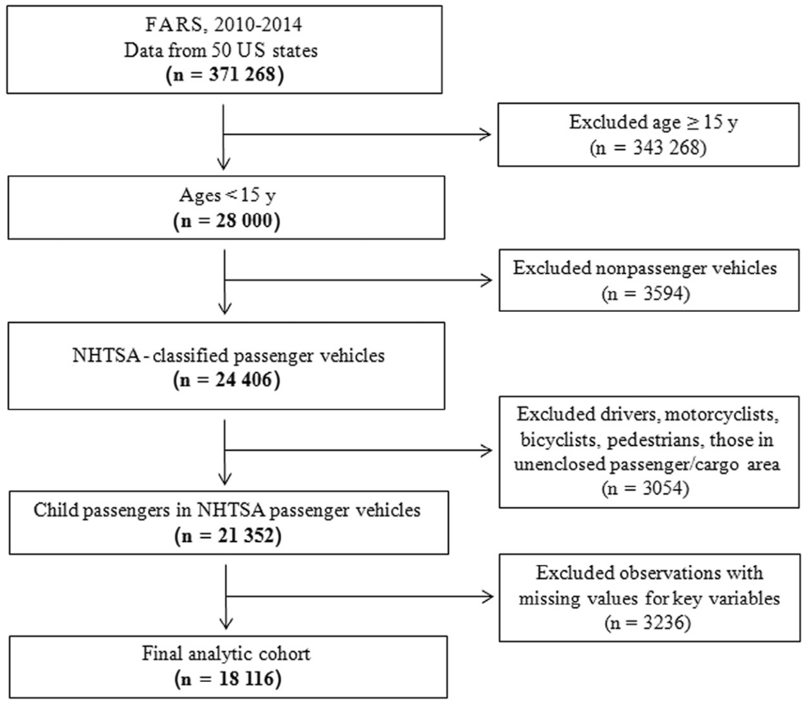

Figure 1. Study population. NHTSA, National Highway Transportation and Safety Administration.

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Table III. Deaths and age-adjusted mean mortality rates per 100 000 children by state, 2010-2014

States	Number involved in a crash	Deaths	Percentage died (%)	Mortality rate per 100 000 children per year*
Midwest	3468	585	17	0.89
Illinois	473	75	16	0.60
Indiana	313	72	23	1.10
Iowa	123	33	27	1.10
Kansas	249	51	20	1.69
Michigan	417	60	14	0.65
Minnesota	178	38	21	0.71
Missouri	539	89	17	1.50
Nebraska	86	26	30	1.30
North Dakota	55	11	20	1.76
Ohio	707	83	12	0.75
South Dakota	54	13	24	1.52
Wisconsin	274	34	12	0.62
Northeast	1365	189	14	0.38
Connecticut	84	11	13	0.34
Maine	42	7	17	0.68
Massachusetts	77	14	18	0.25
New Hampshire	60	5	8.3	0.48
New Jersey	232	26	11	0.32
New York	257	51	20	0.29
Pennsylvania	567	67	12	0.60
Rhode Island	18	3	17	0.33
Vermont	28	5	18	1.02
South	9452	1550	16	1.34
Alabama	551	125	23	2.71
Arkansas	349	51	15	1.72
Delaware	36	5	14	0.58
Florida	1235	144	12	0.88
Georgia	788	130	16	1.26
Kentucky	457	73	16	1.71
Louisiana	417	81	19	1.76
Maryland	205	35	17	0.62
Mississippi	448	99	22	3.23
North Carolina	914	132	14	1.40
Oklahoma	467	80	17	2.02
South Carolina	467	63	13	1.39
Tennessee	671	97	14	1.57
Texas	2017	346	17	1.17
Virginia	260	55	21	0.73
West Virginia	170	34	20	2.16
West	3831	561	15	0.76
Alaska	37	4	11	0.50
Arizona	520	75	14	1.09
California	1574	200	13	0.53
Colorado	333	55	17	1.07
Hawaii	56	9	16	0.70
Idaho	150	33	22	1.90
Montana	131	21	16	2.23
Nevada	157	21	13	0.75
New Mexico	256	43	17	1.98
Oregon	156	23	15	0.64
Utah	216	37	17	0.97
Washington	169	22	13	0.33
Wyoming	76	18	24	3.06
US Overall	18 116	2885	16	0.94

*Mortality rates are age-adjusted with standardization by the total US population within each age group. Reported rates are an average of the yearly rates from 2010 to 2014 for each state.

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